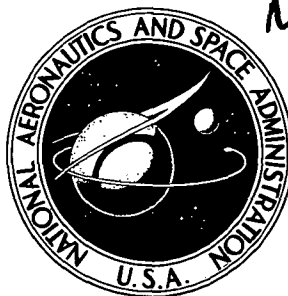


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**INVESTIGATION OF
THE IONOSPHERE AND METEORS**

Edited by I. B. Biybosunov

"Ilim" Press, Frunze, 1971

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Edited by I. B. Biybosunov

Translation of "Issledovaniye ionosfery i meteorov."
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ANNOTATION

Articles included in the collection are the result of investigations in the International Year of the Quiet Sun program. Basic data are presented on ionospheric wind conditions in the meteor zone and equipment for radar observation of meteor trail drift.

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CIRCULATION OF AIR MASSES IN THE UPPER ATMOSPHERE
DURING THE IQSY

I. B. Biybosunov, K. A. Karimov

ABSTRACT. Results of measurements made during the period 1964-1965 are presented.

Ionospheric Wind Conditions

One of the basic tasks of making radar observations of meteors during /3* the International Year of the Quiet Sun (IQSY) was the study of the principles of air mass movement in the meteor zone, since the investigation of upper atmosphere circulation is of great significance in solving a number of problems in geophysics and in the mastery of space. Beginning in June 1964, regular monthly measurements were made of the drift velocity of meteor trails at altitudes from 80 to 110 km, at Frunze in the Radiometeor Laboratory of the Institute of Physics and Mathematics, using a specially designed radar installation.

This article describes some results of measurements made during 1964-1965.

The radar equipment used for the experiment had the following fundamental parameters: carrier frequency $f = 39.5$ MHz, transmitter pulse power $P_u = 30-50$ kW, radar pulse repetition frequency $F = 100-200$ pps, main pulse width $\tau = 8-10$ μ sec, receiver sensitivity $\alpha = (3-5) \cdot 10^{-14}$ W. Reception and transmission were by separate five-channel antennas of the "wave channel" type (two antennas, supplied in-phase) raised to a height of $h = \lambda/2$ above the earth's surface. The receiving and transmitting antennas were 100 to 150 meters apart. A detailed description of the installation is given in reference [1].

Measurements were made in two directions according to a special IQSY program over a six to eight day period in the last ten days of each month. During this time winds in the south-north and west-east directions were studied. North (N) and east (E) were taken as positive.

* Numbers in the margin indicate pagination in the foreign text.

The signals reflected from the meteor trails were recorded on motion picture film, running continuously in front of the screens of cathode ray tubes. Signals were intensified upon arrival of a meteor echo. /4

The radial component of meteor trail drift velocities based on Doppler periods, determined from the photography,

$$V_r = \lambda / 2T_g$$

was found. Here λ is the radar wavelength, and T_g is the period of phase fluctuation in signals reflected from the trail.

The direction of trail displacement was determined by mixing the Doppler signal phases (lead or lag) in two phase channels of a detector. The voltage was supplied to the second phase detector with a phase shift of 90° .

Ionospheric winds in the meteor zone were assumed to be horizontal with an accuracy within a few degrees [2]. The horizontal components of the drift velocity were calculated by using the formula

$$V = V_r / \cos \Theta,$$

from which Θ , the angle of elevation of a reflecting point on the meteor trail, was found as

$$\Theta = \arcsin(h_{\text{char}}/R),$$

where

R is the slant range to the trail;

h_{char} is the mean characteristic altitude, in our case equal to 93 km.

From 2000 to 5000 values of drift velocities were obtained for each direction. Hourly values of the horizontal velocity components were averaged over several days in each direction. Thus, the number of combined values ranged from 30 to hundreds per hour. The more reliable results were obtained during the night and morning hours, when the number of recorded meteors was at a maximum.

The mean hourly wind velocity values obtained were subjected to harmonic analysis, the results of which are listed in Table 1. Each equation in the table contains four terms: a constant term, characterizing the preferred /6

wind direction, a 24-hour, a 12-hour, and an 8-hour component. Amplitudes of higher harmonics (6-4 hours) are smaller as compared to the second and first, and can be ignored in the second approximation. We described our wind measurement procedures in reference [3].

TABLE I *

Month	Direction	Type of equation
1964		
June	N—S	$3,5 + 7,4 \sin 15 (t + 3,5) + 19,7 \sin 30 (t + 7,5) + 2,7 \sin 45 (t + 4,2)$
	E—W	$0,8 + 4,5 \sin 15 (t + 20,6) + 15,9 \sin 30 (t + 5,6) + 7,3 \sin 45 (t + 4,7)$
August	N—S	$16,3 + 25,1 \sin 15 (t + 4,1) + 7,1 \sin 30 (t + 6,5) + 9,8 \sin 45 (t + 3,3)$
	E—W	$11,2 + 18,3 \sin 15 (t + 9,4) + 28 \sin 30 (t + 6,0) + 2,0 \sin 45 (t + 1,2)$
September	N—S	$4,8 + 9,7 \sin 15 (t + 16,7) + 16,4 \sin 30 (t + 11,6) + 13,0 \sin 45 (t + 5,7)$
	E—W	$14,2 + 11,5 \sin 15 (t + 2,0) + 18,7 \sin 30 (t + 7,0) + 8,4 \sin 45 (t + 3,0)$
October	N—S	$-2,8 + 1,9 \sin 15 (t + 12,0) + 17,7 \sin 30 (t + 10,0) + 4,2 \sin 45 (t + 1,0)$
	E—W	$19,8 + 12,2 \sin 15 (t + 4,8) + 14,7 \sin 30 (t + 7,1) + 13 \sin 45 (t + 2,4)$
November	N—S	$4,5 + 13,2 \sin 15 (t + 4,1) + 9,6 \sin 30 (t + 8,6) + 2,8 \sin 45 (t + 7,4)$
	E—W	$15,6 + 7,5 \sin 15 (t + 15,8) + 8,2 \sin 30 (t + 6,6) + 8,9 \sin 45 (t + 4,5)$
December	N—S	$15,0 + 13,9 \sin 15 (t + 4,5) + 17,8 \sin 30 (t + 7,4) + 12,2 \sin 45 (t - 1,4)$
	E—W	$2,1 + 5,6 \sin 15 (t + 19,8) + 25,1 \sin 30 (t + 4,2) + 1,3 \sin 45 (t + 0,4)$

* Commas represent decimal points.

Let us review the results of ionospheric wind velocities individually for each year. In 1964, the investigations were conducted in June, but technical reasons prevented ionospheric wind velocities from being measured in July.

Figure 1 and Table 1 show drift histograms and list their corresponding equations for 1964, from which it will be seen that the amplitudes of the 24-hour components vary differently for different months, from $A_1 = 2$ m/sec to $A_1 = 25$ m/sec; those of the 12-hour components vary from $A_2 = 7$ m/sec to $A_2 = 28$ m/sec.

The preferred direction is east for the west-east component in the prevailing wind, with the maximum air mass transport velocity 20 m/sec.

The zonal components of the prevailing vectors are directed towards the north.

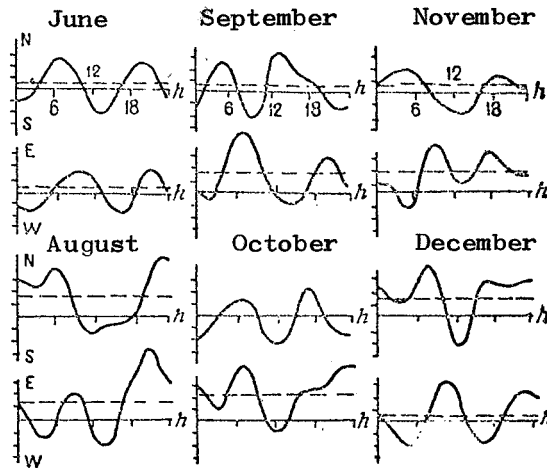


Figure 1. Histograms of meteor trail drifts for 1964.

Figure 2 shows the polar diagrams of changes in the vectors of the 24-hour, 12-hour, and 8-hour components over a 24-hour period.

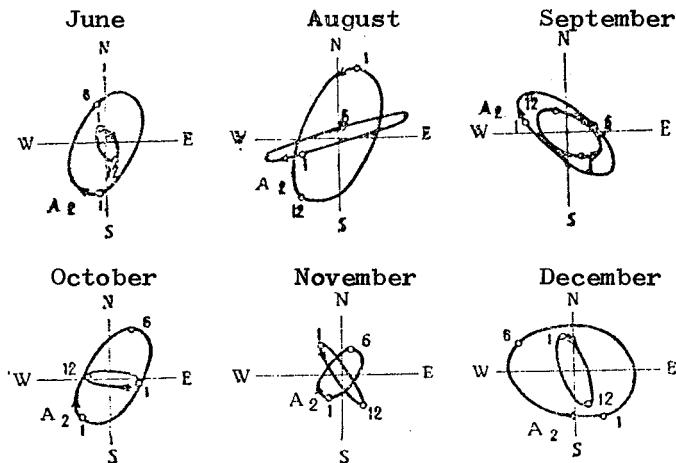


Figure 2. Polar wind diagrams for 24-hour and 12-hour components.

The rotation of the vector of the 12-hour component is clockwise. /7
The 24- and 8-hour components have no general behavior patterns.

Thus, in the given latitude for the place (the coordinates of the range in which the SOM-1 radar was located in Frunze were $\varphi = 72^{\circ}35'$, $\lambda = 42^{\circ}56'$), at altitudes of 80-110 km, a large stream of air is transported primarily to

the east relative to the earth, at an average velocity of the order of 30 m/sec.

Let us review the experimental data obtained by the SOM-1 radar in 1965.

Figure 3 shows histograms of meteor trail drifts for January through December, inclusive.

Measurements were made for six to eight days on the days indicated in the IQSY program. Lines calculated using the harmonic analysis method and taking three harmonics into consideration are shown solid. The equations for all the curves for 1965 are listed in Table 2.

Analysis of the equations shows that the most significant harmonic is the 12-hour, with maximum amplitude $A_2 = 20$ m/sec.

The amplitude of the 24-hour harmonic is a maximum of $A_1 = 16$ m/sec.

The amplitudes of the 12-hour and 24-hour harmonics have a seasonal variation, with maximum values occurring during the summer.

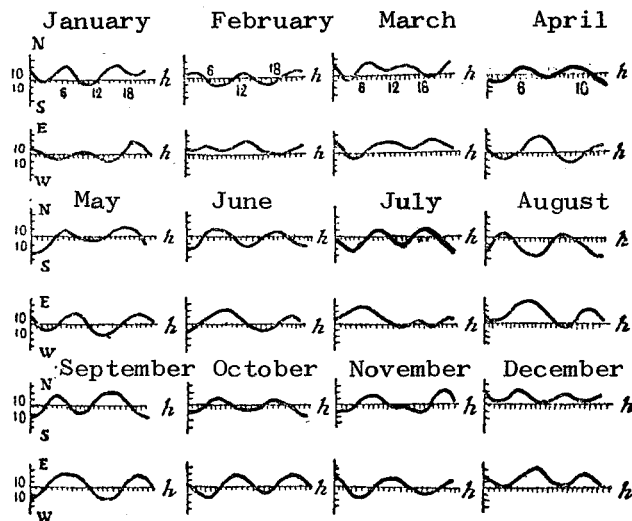


Figure 3. Histograms of meteor trail drifts for 1965.

The ratio of mean amplitudes of 12-hour to 24-hour harmonics for meteor altitudes is

$$K = (\bar{A}_2 / \bar{A}_1) \simeq 3$$

/8

The amplitude of the 8-hour harmonic is of the order of the 24-hour harmonic amplitude and has no seasonal variations.

Figure 4 shows the polar diagrams of the rotation of the vector for the 24- and 12-hour harmonics for analyzing the phase relationships of the zonal and meridional components. The 24-hour component vector experiences no regular changes during the year. Clockwise, as well as counterclockwise, rotation is observed. The 12-hour harmonic vector rotates clockwise throughout the year, except in March and July.

The polar diagrams for the 12-hour components show that in fact the northern component always leads to the east, as distinct from the 3-hour component.

The 12-hour wind component is directed largely northward 0600 throughout the year.

TABLE 2 *

Month	Direction	Type of equation
1965		
January	N-S	$10,0 + 6,0 \sin 15 (t + 7,5) + 11,0 \sin 30 (t + 8,5) + 9,0 \sin 45 (t + 2,2)$
	E-W	$0,5 + 9,2 \sin 15 (t + 6,4) + 10,8 \sin 30 (t + 4,2) + 4,6 \sin 45 (t + 5,8)$
February	N-S	$-2,4 + 5,0 \sin 15 (t + 4,6) + 9,5 \sin 30 (t + 3,1) + 5,0 \sin 45 (t + 6,8)$
	E-W	$7,5 + 4,0 \sin 15 (t + 20) + 7,1 \sin 30 (t + 2,1) + 1,9 \sin 45 (t + 3,8)$
March	N-S	$8,0 + 5,1 \sin 15 (t + 20) + 4,5 \sin 30 (t + 5,4) + 12 \sin 45 (t + 2,4)$
	E-W	$7,9 + 9,1 \sin 15 (t + 13) + 8,9 \sin 30 (t + 4,8) + 3,7 \sin 45 (t + 0,7)$
April	N-S	$-0,4 + 10,0 \sin 15 (t - 17,4) + 16,0 \sin 30 (t + 8,2) + 4,7 \sin 45 (t + 6,3)$
	E-W	$-2,1 + 5,6 \sin 15 (t + 1,2) + 11,0 \sin 30 (t + 4,6) + 5,5 \sin 45 (t + 2,8)$
May	N-S	$-5,8 + 11,0 \sin 15 (t + 15,6) + 12,8 \sin 30 (t + 7,4) + 6,3 \sin 45 (t + 4,4)$
	E-W	$0,5 + 2,1 \sin 15 (t + 23,1) + 16,2 \sin 30 (t + 5,6) + 4,6 \sin 45 (t + 1,0)$
June	N-S	$-6,0 + 5,0 \sin 15 (t + 17,0) + 14,3 \sin 30 (t + 8,2) + 8,9 \sin 45 (t + 4,1)$
	E-W	$3,0 + 11,7 \sin 15 (t + 22,2) + 18,2 \sin 30 (t + 6,9) + 4,2 \sin 45 (t + 6,5)$
July	N-S	$-8,0 + 7,9 \sin 15 (t + 13,1) + 20,3 \sin 30 (t + 7,3) + 11,0 \sin 45 (t + 0,5)$
	E-W	$11,0 + 16,1 \sin 15 (t + 23,9) + 13,4 \sin 30 (t + 7,1) + 4,4 \sin 45 (t + 2,8)$
August	N-S	$-17,6 + 2,3 \sin 15 (t + 12,3) + 16,7 \sin 30 (t + 10,7) + 3,2 \sin 45 (t + 6,5)$
	E-W	$17,6 + 15,2 \sin 15 (t + 23,0) + 21,5 \sin 30 (t + 5,4) + 7,8 \sin 45 (t + 5,2)$
September	N-S	$3,0 + 8,9 \sin 15 (t + 15,8) + 15,6 \sin 30 (t + 9,4) + 12,1 \sin 45 (t + 4,9)$
	E-W	$-2,0 + 5,8 \sin 15 (t + 2,9) + 7,4 \sin 30 (t + 7,5) + 5,6 \sin 45 (t + 3,0)$
October	N-S	$-5,1 + 3,8 \sin 15 (t + 21,6) + 10,7 \sin 30 (t + 9,0) + 4,8 \sin 45 (t + 5,5)$
	E-W	$0,9 + 1,3 \sin 15 (t + 7,2) + 21,3 \sin 30 (t + 4,9) + 3,6 \sin 45 (t + 6,3)$
November	N-S	$-1,6 + 1,6 \sin 15 (t + 21,0) + 13,5 \sin 30 (t + 5,4) + 6,3 \sin 45 (t + 4,6)$
	E-W	$-0,8 + 3,4 \sin 15 (t + 19,2) + 14,8 \sin 30 (t + 3,0) + 5,4 \sin 45 (t + 1,6)$
December	N-S	$14,2 + 2,6 \sin 15 (t + 5,8) + 4,7 \sin 30 (t + 8,7) + 9,0 \sin 45 (t + 2,3)$
	E-W	$11,0 + 6,1 \sin 15 (t + 2,2) + 12,5 \sin 30 (t + 5,4) + 5,7 \sin 45 (t + 7,1)$

* Commas represent decimal points.

Regular changes do not occur in the 8-hour component vector.

These results agree in general with those obtained by the Khar'kov group [4, 5].

Analysis of the prevailing wind for the north and east components for 1964 and 1965 (Figure 5) reveals that the meridional component (E - W) is primarily directed eastward, with maximum amplitude in the summer and winter months $A_0 = 12$ m/sec. The minimum amplitude occurs in the spring-fall months.

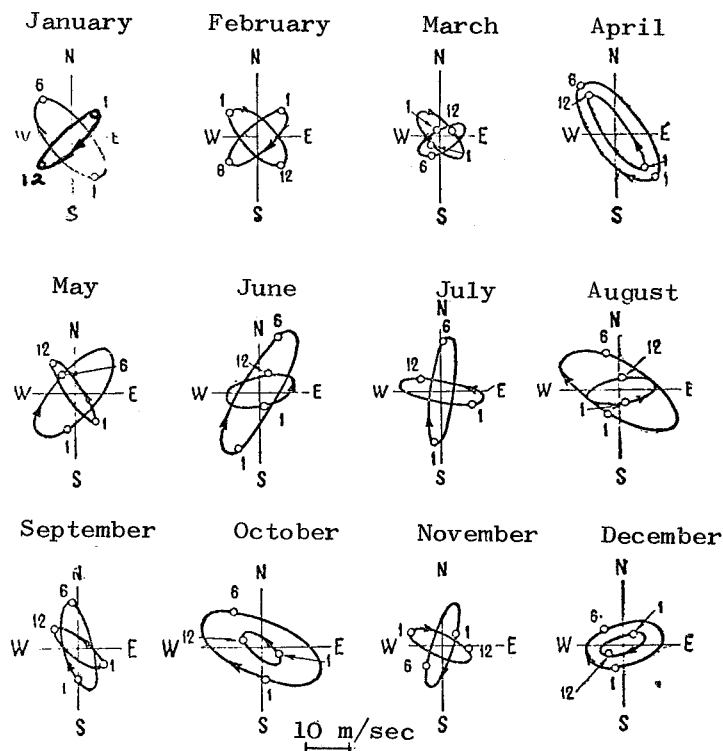


Figure 4. Polar diagrams of 24-hour and 12-hour component vectors.

Characteristic of the zonal (N-S) component in the summer months is the transport of the air masses in a southerly direction, with the maximum velocity 10 m/sec.

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There is a change in vector direction in the spring-fall months; movement of the air masses is toward the pole.

The difference in temperatures in the upper atmosphere over the polar and equatorial regions affects the zonal component.

The southern component should predominate in the summer months.

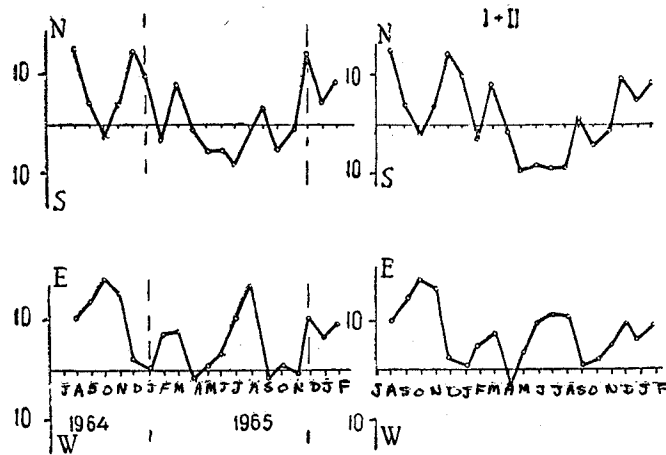


Figure 5. Prevailing wind direction, 1964-1965.

Temperature gradients, as well as the effect of the earth's rotation, caused by kinematic viscosity, and equal to the ratio

$$\eta/\rho$$

where η is the coefficient of friction, and ρ is density of the atmosphere at the corresponding altitude [6], affect the wind direction in the meridional region.

The results fit the model of atmospheric circulation on a global scale suggested by A. Kochanski [7] in 1963 quite well.

It should be pointed out that the 1965 data on atmospheric circulation are more reliable.

The presence of a significant amplitude in the 12-hour harmonic indicates the resonant nature of atmospheric oscillations at these altitudes. The presence of a cold region with a temperature minimum at altitudes of the order of 95 km, that is, the presence of temperature troughs in the atmosphere along the vertical, leads to the occurrence of free atmospheric oscillations with a period of 12 hours.

Thus, the effect of the semidiurnal solar gravitational force increases because of the resonance of the atmosphere at these altitudes.

The resonance theory was suggested by Wilkes [8] and developed in detail by White [9].

In conclusion, it should be noted that questions of atmospheric circulation at altitudes above 80 km require further detailed study, and year-to-year comparisons.

Annual Cycle of Turbulence Intensity

The kinetic energy of turbulent motions in a unit mass

$$I = 1/2 (\overline{U'_x}^2 + \overline{U'_y}^2 + \overline{U'_z}^2),$$

where $U'_i = U_i - \bar{U}_i$ is the pulsation, or the turbulent velocity, and i is the component of the measured value of the velocity in the specified direction, can be taken as the turbulence intensity.

The distribution of pulsation velocities at a fixed point must be close to normal (Gaussian). In the case of radio meteor measurements, the velocity values depend on different points within a volume bounded by the width of the antenna radiation pattern and the thickness of the meteor layer.

What follows from the theory of turbulence is that turbulent energy is defined by the density gradient, $d\rho/dz$, which has a seasonal pattern, and by the mean wind gradient, which affects temporal changes in turbulence intensity.

Turbulence intensity was calculated for each hour, using the formula:

$$I = 1/2 (\overline{U'_x}^2 + \overline{U'_y}^2)$$

when there were no vertical pulsation velocities. It should be pointed out that $\overline{U'_z}^2$ may increase by 15-30% and distort the value of the overall intensity.

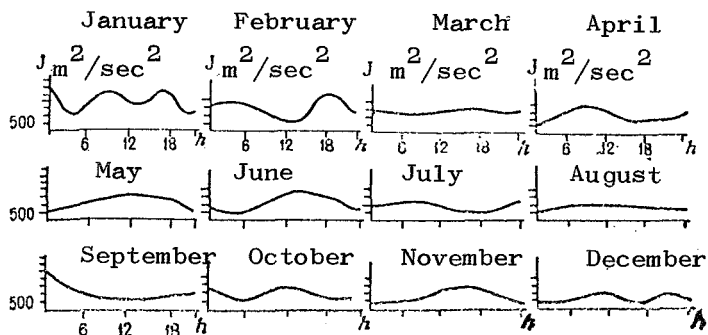


Figure 6. Diurnal changes in turbulence intensity in 1965.

Figure 6 shows the diurnal changes in intensity for the 12 months of 1965, and for January 1966. There is a daily pattern for some months (January, May, June, November) with a maximum with a mean error of $\sigma J = 400 \text{ m}^2/\text{sec}^2$ during the daytime, but a tendency toward a maximum during the night hours is characteristic of other months (February, April, September). There was no behavior pattern to be observed for the other months, i.e. the vector of pulsation intensity is constant throughout the 24 hours. Solar corpuscular radiation probably is the responsible factor for this effect.

The processing of wind data must include the daily J pattern when there are daily changes in J.

Figure 7 shows the annual turbulence intensity pattern for 1965.

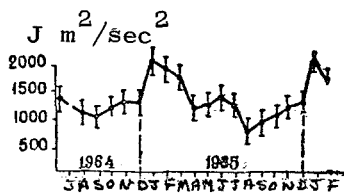


Figure 7. Seasonal change in turbulence intensity.

An annual pattern, with an intensity minimum during the summer ($J = 710 \text{ m}^2/\text{sec}^2$ in August) and an intensity maximum during the winter ($J = 2400 \text{ m}^2/\text{sec}^2$), will be seen quite clearly. The mean error in J is of the order of $\sigma J = 200 \text{ m}^2/\text{sec}^2$.

The data on annual change in turbulence intensity concord with the results obtained by the Kazan group, and can be explained

by the different effects of the Archimedean forces in the summer and winter [10].

Time Constant and the Horizontal Scale for Strong Vortices

It is believed that irregular motions in the meteor zone are the result of the turbulization of the laminar air streams produced by forces of hydrodynamic origin. Experience shows that the wind velocity, measured in layers several kilometers apart in altitude, sometimes differs by tens of meters per second. This indicates the presence of a turbulent wind gradient. The mean value of the turbulent wind gradient, according to

reference [11], is

$$\text{grad}U = dU/dh = 8.5 \text{ m/sec per km.}$$

The fundamental parameters characterizing turbulent motion are the rate of arrival of energy, ϵ , from outside sources, the pulsation velocity, U' , for large-scale vortices, the size of the vortices, L , and the lifetime of the vortices, T .

The procedure for estimating the quantities U' , L , and T has been given by Greenhow and Neufeld [12], as well as by Delov, Lagutin, and Lysenko [11]. The values found were $U' = 28 \text{ m/sec}$, $T = 110 \text{ min}$, and $L = 180 \text{ km}$.

The authors did the work of evaluating the influence of U' , L , and T in the heart of continental Asia and of comparing these magnitudes with those found earlier. The evaluation was made using the preceding procedure (an autocorrelation function was calculated from pulsation velocities averaged for 30-minute intervals, with a limited range sample for 24-hour intervals) of the form

$$R(T) = \frac{\sum_{t=1}^n U(t) \cdot \sum_{t=1}^n U(t+\tau)}{\left[\sum_{t=1}^n U^2(t) \cdot \sum_{t=1}^n U^2(t+\tau) \right]^{1/2}}; \tau=0,1,\dots,n,$$

as well as G. Teptin's procedure [10]. The autocorrelation function was calculated for a fixed point of the form

$$R(T) = \frac{\sum_{t=1}^n U'(\bar{r}, t) \sum_{t=1}^n U'(\bar{r}, t+\tau)}{\left[\sum_{t=1}^n U'^2(\bar{r}, t) \sum_{t=1}^n U'^2(\bar{r}, t+\tau) \right]^{1/2}}; \tau=0,1,\dots,n,$$

where $U'(\bar{r}, t)$ is the turbulent velocity at the fixed point with coordinates $\bar{r}$ at time t . In addition to the autocorrelation function for the point, the autocorrelation for shower meteors was calculated (for a statistical check).

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The number of meteors drops significantly when the radiation pattern is narrowed because the single-point meteor radar method does not permit measuring small-scale turbulence characteristics. The characteristics of turbulent motion change during extended radar observations so it is necessary to confine the measurements to the streams. At the same time, the majority of the reflecting points lie in a single plane, the echo plane, which passes through the radar perpendicular to the direction of the radiant. In this case there is no need to measure the azimuths of the angles of reflection when calculating the specular reflection, and the selection of the work area for averaging can be made out to radar range. In our case, the horizontal area had a maximum limit of 30 km. $\Delta R \leq 30$ km. Altitudes were determined with respect to the coefficient of ambipolar diffusion, $D = f(h)$

$$\lg D = 0.067 \cdot h - 5.6.$$

The scatter of altitude points was $\Delta h = \pm 3$ km, using Greenhow's method [14].

Reflecting points in the altitude interval $\Delta h \leq 8$ km then were selected. Thus, the size of the region was contained in an area $\Delta R \leq 30$ km and $\Delta h \leq 8$ km.

The following streams were used to evaluate the characteristics:

- 21 - 22 October 1965 (Orionids)
- 16 - 17 November 1965 (Leonids)
- 2 - 3 January 1966 (Quadrantids)

The autocorrelation function was calculated in unit values of pulsation velocities for two to three hour time intervals (Figure 8).

The autocorrelation function transition time, T_0 , at "zero" characterizes the time constant for strong vortices. The heterogeneity lifetime, determined in unit values for the "point," is

$$\begin{aligned} \tau_0 &= 30 \text{ min (Orionids)} \\ \tau_0 &= 25 \text{ min (Quadrantids)} \end{aligned}$$

Correspondingly, $T = \tau_0$, calculated for a sporadic background over a 24-hour interval for averaged 30-minute interval velocities, is

$\tau_0 = 80 \text{ min}$ (22 October 1965);
 $\tau_0 = 70 \text{ min}$ (3 January 1966).

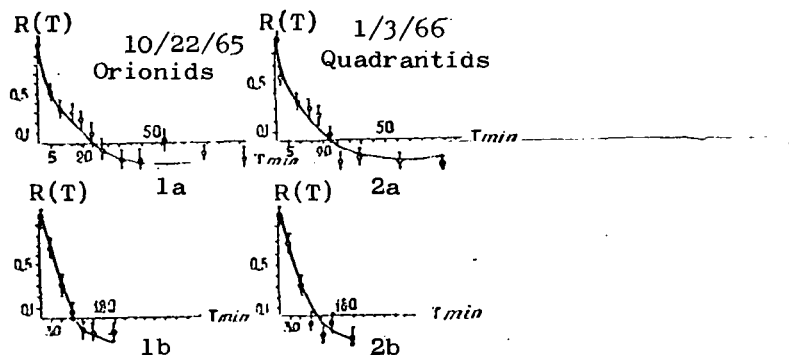


Figure 8. Autocorrelation function curves. 1a, 2a - in unit values; 1b, 2b - 30 minute averages.

The evaluation of the horizontal dimensions of strong vortices was made using the formula

$$L_r = (\overline{U'}^2)^{1/2} \cdot \tau_0$$

for known $\overline{U'}$ and τ_0 for the streams

$L_r = 36 \text{ km}$ - October (Orionids);

$L_r = 30 \text{ km}$ - January (Quadrantids).

The sizes of the nonuniformities for the sporadic meteors case for a 24-hour period, averaged for 30-minute intervals, were

$L_r = 80 \text{ km}$ - October;

$L_r = 120 \text{ km}$ - January.

In our opinion, a size of the order of 30-36 km is more probable for large-scale vortices.

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The results of the determination of τ_0 equal to 70-80 min are far too high because the component attributable to the presence of periodic wind components over a 24-hour period are superimposed on the exponential decrease in $R(T)$, as well as to the influence of the antenna radiation pattern (influence of the region illuminated by the radar antenna). The question of the degree of influence exerted by the antenna radiation pattern is still unresolved. Attenuation of the autocorrelation function shows that fluctuations in wind velocity are a combination of fluctuations of a turbulent character and periodic oscillations with random amplitudes and phases.

The magnitudes α and β can be calculated during the approximation of the autocorrelation function by the expression

$$R(t) = R_0 \cdot e^{-\alpha \Delta t} \cos \beta \Delta t.$$

If $\beta > \alpha$, the periodic oscillations with random amplitudes and phases make a definite contribution to the spectral density of the velocity distribution at frequencies close to τ_0 . If $\beta < \alpha$, the principal role in this process is played by velocity fluctuations of a turbulent character [15]. The autocorrelation function (see Figure 8; 1a and 2a) has the form

$$\begin{aligned} R(t) &= R_0 \cdot e^{-0.11t} \cdot \cos 0.06t \text{ (Orionids);} \\ R(t) &= R_0 \cdot e^{-0.12t} \cos 0.05t \text{ (Quadrantids),} \end{aligned}$$

where wind velocity fluctuations of a turbulent character are of primary significance.

Analogous autocorrelation functions (see Figure 8; 1b and 2b) can be expressed by the equations

$$\begin{aligned} R(t) &= R_0 \cdot e^{-0.18t} \cos 0.30t \text{ (Orionids);} \\ R(t) &= R_0 \cdot e^{-0.15t} \cdot \cos 0.28t \text{ (Quadrantids).} \end{aligned}$$

The α and β relationship shows how significant are the effects of periodic wind fluctuations over a 24-hour period, leading as they do to an increase in the time of existence of discontinuity τ_0 .

The magnitude of the time constant τ for large-scale vortices of the order of 25-30 min agrees with Teptin's recent data [10].

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The connection between time and space spectra is described by J. Taylor's hypothesis, and by the hypothesis of conservation of perturbation form without significant alterations when movement is along a straight line with air streams with mean stream velocity, by the so-called "frozen turbulence" hypothesis, which has been proven for small scales.

The fluctuations in hydrodynamic magnitudes at some point can be used to judge the pulsations along a straight line passing through this point in the direction of the mean wind. In fact, the turbulence field is not frozen, and its configuration undergoes temporal distortion. If the turbulent

energy is far less than the mean motion energy, the errors caused by using the "frozen turbulence" hypothesis to describe the structure of the turbulence field will be small. They will be significant when the energy of turbulent pulsations is commensurate with the averaged motion energy. This hypothesis provides wind velocity values at one fixed moment in time for different points and for different moments in time. A structural function of the type

$$D_{rr}(r_*) = \Delta \bar{U}^2_r.$$

was calculated to evaluate the horizontal dimensions of "frozen" vortices.

Pairs of points at approximately the same altitude were grouped by distance between points found by the "frozen turbulence" hypothesis for a fixed moment in time. The differences in the horizontal velocity components were calculated for these points with the mean wind vector taken into consideration.

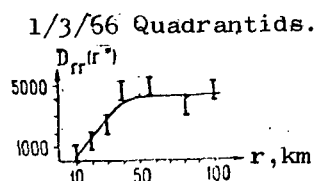


Figure 9. Structural function curve.

Figure 9 is the structural function, $D_{rr}(r_*)$, curve, plotted for the January Quadrantids, where we see that the horizontal turbulence scale is in the limits of 30-40 km. This dimension agrees with data for the autocorrelation function with respect to unit values for the Quadrantids and Orionids.

Thus, the correlation of velocities in "frozen turbulence" is seen to be in the limits of 30-40 km. These data agree with optical observations by Savrukhin and Gul'medov. /19

The rotation of individual clusters of meteor trails results in an increase in vortex size of the order of 20-50 km [16].

Conclusion

1. Observed during 1964-1965 in the upper atmosphere at altitudes of 80-115 km was the steady transport of air masses in a southeasterly direction; with mean velocities up to 15 m/sec in the summer.

What is primarily a northeasterly transport of the air masses is characteristic in the winter.

2. Mean wind values show changes in oscillation amplitude over a 24-hour period, with the most significant harmonic oscillations with a 12-hour period and an amplitude reaching 40 m/sec.

3. The magnitude of turbulence intensity has a clearly defined seasonal pattern, and is greater in the winter than in the summer by a factor of three.

4. Our assessment of the dimensions of large-scale nonuniformities indicates that the horizontal scale of the turbulence, or the radius of the correlation of drift velocities, is in the limits of 30-40 km.

REFERENCES

1. Karimov, K., Kostromin, V., Berezovskiy, M., "Radar Equipment for Observing Meteors in Kirghizia," Sb.: Meteornoye rasprostraneniye radiovoln [In collection: Meteor Propagation of Radio Waves], No. 3, Kazan', 1966.
2. Dokuchayev, V. P., "The Influence of Geomagnetic Disturbances of the Drift of Ionized Gas," Izv. VUZov, Radiofizika, No. 3, 1960.
3. Biybosunov, I., Karimov, K. A., "Wind Conditions in the Ionosphere Over Kirghizia," Sb.: Meteornoye rasprostraneniye [In collection: Meteor Propagation], 1966.
4. Kashcheyev, B. L., Lebedinets, V. N., "Radar Investigation of Meteor Phenomena," MGG, 7, 1961.
5. Lysenko, I. A., "Air Flows in the Meteor Zone from Radar Observation," Astronomicheskii zhurnal, No. 21, 1963.
6. Mitra, S. K., Verkhnyaya atmosfera [The Upper Atmosphere], IL, 1959.
7. Kochanski, A., "Circulation and Temperatures at 70 to 100 kilometer Height," J. Geophys. Res., 68, 1963, 213.
8. Wilkes, M. V., Oscillations of the Earth's Atmosphere, Cambridge, 1949.
9. White, M., "Thermal and Gravitational Atmospheric Oscillations-Ionospheric Dynamo Effects Included," I. Atmos. Terr. Phys., 17, 1960, 3.
10. Zadorina, Pokrovskiy, Sidorov, Teptin, Fakhrutdinova, "Atmospheric Motion at Altitudes of 80-100 km from Radio Meteor Observations in Kazan'," Izv. AN SSSR, seriya fizika atmosfery i okeana, No. 1, 1967. /20
11. Delov, I., Lagutin, M., Lysenko, N., "Investigation of Certain Parameters of Turbulent Motion Using Radar Observation of Meteor Trails," Izv. VUZov, Radiofizika, Gorkiy, 1964.

12. Greenhow, J., Neufeld, E., "Measurement of Turbulence in the Upper Atmosphere," Proceeding Phys. Soc., 74, 1959.
13. Greenhow, J., Hall, I., "Diurnal Variations of Density and Scale Height in the Upper Atmosphere," J. Atmosphere Terr. Phys., Vol. 18, 1960, 205.
14. Pinus, Ye., "Energy Spectra of Pulsations in Wind Velocity in the Free Atmosphere," Meteorologiya i gidrologiya, No. 4, 1966.
15. Gul'medov, Kh., "Upper Atmosphere Turbulence from Optical Observations of Meteor Trails in Ashkhabad and Kazan'," Geomagnetizm i aeronomiya, Nos. 2, 3, 1963.

THE USE OF TWO SPACED RADARS TO MEASURE METEOR DRIFTS

K. A. Karimov, V. V. Sidorov

ABSTRACT. Radar was used in Frunze in 1964-1965 to study meteors in order to evaluate the accuracy of wind parameters measured in the meteor region of the atmosphere for small samples and unknown altitudes, as well as to evaluate the effect of using different space and time averaging methods on the accuracy of results obtained.

The investigations covered the 18-month period of observations in the International Year of the Quiet Sun program. They were made using two simultaneously operating radars, spaced 200 km apart in longitude, the antennas of which illuminated the same general region of the atmosphere, or regions spaced up to 500 km apart. The averaged wind characteristics, as obtained by the two radars 200 km apart, were compared. This spacing obviously is not significant from the geophysical point of view (the local time differs by 10 min), but in this case, the possibility of working with common meteors is, for all practical purposes, eliminated, so, independent samples of drift velocities can be obtained. /21

All published information on wind characteristics in the meteor zone was obtained under the assumption that the averaged wind characteristics do not vary over distances of the order of 300 to 500 km. This position requires experimental verification, however. Hence, the natural question is how quickly do averaged wind characteristics change with longitude, and what is the connection between this and the region of averaged individual measurements?

Equipment and Observation Procedure

Measurements of the drifts of meteor trails were made using specially built radar and the coherent pulse method at a frequency of 39.5 MHz. The frequency of the second radar was shifted 4-5 bandwidths with respect to the first. Reception and transmission were accomplished with a system of two five-element broadside antennas of the "wave channel" type, with a pattern width in the horizontal plane of 25° at the 3 db level. Transmitter power (autooscillator) was 50 kW, the pulse repetition frequency was 100 pps, /22

the main pulse width was 10 μ sec, and the sensitivity of the receivers was $5 \cdot 10^{-14}$ W when the bandwidth of the receivers was 100 kHz. Phase synchronization of the reference oscillator was accomplished by locking onto the frequency of the receiver oscillator. A detailed description of the equipment used is given in reference [1].

The observations included four variants to explain differences in measured wind parameters.

Variant 1. The same component of the wind velocity was observed in the same region of the atmosphere, but the antennas were oriented in opposite directions (Figure 1a).

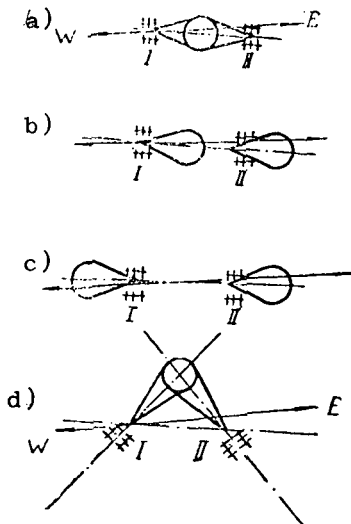


Figure 1. Variants in relative orientations of the antennas for the two radars.

Variant 2. The same wind component was observed with the antennas oriented in the same direction, but in different atmospheric regions (Figure 1b).

Variant 3. Observations were made with opposing antenna orientations and in different regions (Figure 1c).

Variant 4. Observations were made in the same "local" region with simultaneous measurements of two wind components (Figure 1d).

Wind data were processed by an M-20 electronic computer, with allowances made for the statistical weight of each mean hourly velocity. Results were processed primarily in terms of underdense trails. The mean daily number of meteor echoes suitable for measuring Doppler characteristics was of the order of 500.

Results of the Experiments

A good correlation of hourly values of drift velocity ($R > 0.85$) was found for Variant 1 observations, when the same wind velocity component was measured in the same region of the atmosphere (data based on the results of four observation cycles in different months).

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TABLE I *

Month	Station	Type of equation							
January	SOM-I	$0,5 \pm 1,2 + (9,2 \pm 2,4) \sin 15 (t + 6,4) + (10,8 \pm 2,2) \sin 30 (t + 4,2) + (4,6 \pm 1,9) \sin 45 (t + 5,8)$							
	SOM-II	$2,9 \pm 2,0 + (6,9 \pm 3,3) \sin 15 (t + 9,3) + (12,7 \pm 3,1) \sin 30 (t + 4,5) + (9,1 \pm 2,8) \sin 45 (t + 5,9)$							
	I, II	$1,7 \pm 1,8 + (5,9 \pm 2,9) \sin 15 (t + 7,4) + (11,6 \pm 2,8) \sin 30 (t + 4,4) + (7,1 \pm 2,2) \sin 45 (t + 5,4)$							
February	SOM-I	$7,5 \pm 1,4 + (4,0 \pm 2,2) \sin 15 (t + 20) + (7,1 \pm 2,0) \sin 30 (t + 2,1) + (1,9 \pm 1,9) \sin 45 (t + 3,8)$							
	SOM-II	$4,7 \pm 2,2 + (2,9 \pm 3,8) \sin 15 (t + 15) + (9,4 \pm 3,7) \sin 30 (t + 1,2) + (5,4 \pm 3,0) \sin 45 (t + 5,1)$							
	I, II	$6,1 \pm 1,8 + (1,4 \pm 2,5) \sin 15 (t + 20,1) + (7,6 \pm 2,2) \sin 30 (t + 1,6) + (3,4 \pm 2,5) \sin 45 (t + 5,4)$							
March	SOM-I	$7,9 \pm 1,8 + (9,1 \pm 2,6) \sin 15 (t + 13,0) + (8,9 \pm 3,0) \sin 30 (t + 4,8) + (3,7 \pm 1,7) \sin 45 (t + 0,7)$							
	SOM-II	$7,3 \pm 2,3 + (5,9 \pm 5,0) \sin 15 (t + 12,0) + (11,8 \pm 4,9) \sin 30 (t + 5,2) + (5,8 \pm 3,6) \sin 45 (t + 2,4)$							
	I, II	$7,6 \pm 2,0 + (8,3 \pm 3,5) \sin 15 (t + 12,9) + (9,7 \pm 3,0) \sin 30 (t + 5,1) + (2,0 \pm 2,0) \sin 45 (t + 2,1)$							
November	SOM-I	$8,3 \pm 1,6 + (3,8 \pm 2,9) \sin 15 (t + 21) + (13 \pm 3,2) \sin 30 (t + 2,9) + (3,4 \pm 2,6) \sin 45 (t + 0,8)$							
	SOM-II	$5,8 \pm 2,1 + (4,6 \pm 2,8) \sin 15 (t + 23) + (15,5 \pm 2,8) \sin 30 (t + 2,2) + (3,9 \pm 3,0) \sin 45 (t \pm 2,2)$							
	I, II	$7,2 \pm 1,9 + (4,7 \pm 2,5) \sin 15 (t + 12) + (14,1 \pm 3,1) \sin 30 (t + 3,2) + (2,7 \pm 2,2) \sin 45 (t \pm 1,8)$							

* Commas represent decimal points.

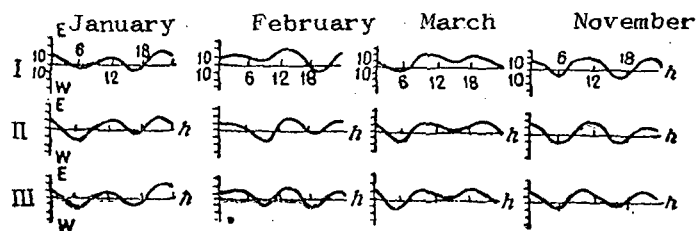


Figure 2. Histograms of drift velocities for Variant 1 observations, as shown in Figure 1a.

Figure 2 shows and Table 1 lists histograms and equations for the corresponding averaged hourly histograms of drift velocities for four months of observations by the two radars for Variant 1 observations, as well as the summed value for the two radars. All subsequent results are reduced to simultaneous observations. /25

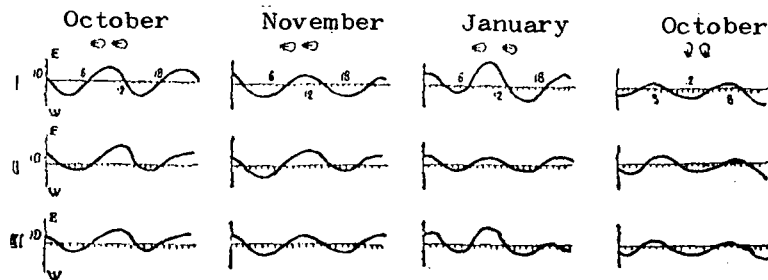


Figure 3. Histograms of drift velocities for Variant 2 observations, as shown in Figure 1b.

The second series of experiments was devoted to an explanation of the dependence of the effect of dispersion of regions of averaging on the measured parameters of the regular wind.

Table 2 lists and Figure 3 shows equations for averaged hourly drift velocity histograms and a summed histogram for the region of averaging of up to 300 km for Variant 2 observations, when the same wind component was measured with identical antenna orientations, but for regions separated by 200 km (conducted for four measurement cycles in different months).

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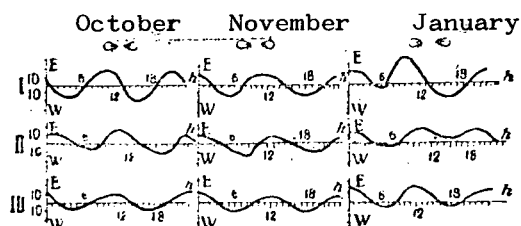


Figure 4. Histograms of drift velocities for Variant 3 observations, as shown in Figure 1c.

Table 3 lists, and Figure 4 shows, equations of averaged hourly drift velocity histograms and summed histograms for the averaging region up to 600 km for 3rd Variant observations, with opposing antenna orientations for regions 500 km apart (three measurement cycles in different months). The question of whether these differences are real values, or simply errors in the observation procedure, requires further study. In the results presented here, however, the A_0 values measured in the regions over the Issyk-Kul' area are systematically higher than over northwestern Kirghizia. It is interesting to note that within area spacings up to 500 km, the daily harmonics appear to be close to opposite in phase, and almost cancel out when averaged in a common zone, so that relative differences appear to be greater. The substantial second harmonic phase shifts (beyond the limits of measurement error) determine the relatively great differences in the amplitudes of the corresponding harmonics.

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The summed differences for the set of mean hourly drift velocity values for the two radars can be estimated from the first correlation moment. The corresponding correlation function was calculated for a closed daily cycle with a time shift.

TABLE 2 *

Month	Station	Type of equation					
October	SOM-I	$-5.1 \pm 2.2 + (4.0 \pm 2.6) \sin 15 (t+21.6) + (10.3 \pm 2.8) \sin 30 (t+9.0) + (4.8 \pm 2.1) \sin 45 (t+5.5)$					
	SOM-II	$-7.0 \pm 2.0 + (7.2 \pm 3.0) \sin 15 (t+20.6) + (12.7 \pm 3.0) \sin 30 (t+8.5) + (4.2 \pm 3.4) \sin 45 (t+5.8)$					
	I, II	$-6.0 \pm 1.9 + (5.5 \pm 2.5) \sin 15 (t+21.3) + (11.6 \pm 2.6) \sin 30 (t+8.8) + (4.5 \pm 3.2) \sin 45 (t+5.6)$					
October	SOM-I	$0.9 \pm 2.8 + (1.3 \pm 2.9) \sin 15 (t+7.2) + (21.3 \pm 4.0) \sin 30 (t+4.9) + (3.6 \pm 4.0) \sin 45 (t+6.3)$					
	SOM-II	$7.7 \pm 2.3 + (1.8 \pm 2.2) \sin 15 (t+12.7) + (12.7 \pm 3.2) \sin 30 (t+2.9) + (2.2 \pm 3.2) \sin 45 (t+4.9)$					
	I, II	$4.3 \pm 2.0 + (5.5 \pm 2.1) \sin 15 (t+7.5) + (15.0 \pm 3.0) \sin 30 (t+4.3) + (2.5 \pm 2.8) \sin 45 (t+5.7)$					
November	SOM-I	$-0.8 \pm 1.6 + (3.4 \pm 2.6) \sin 15 (t+19.2) + (11.0 \pm 3.0) \sin 30 (t+2.8) + (5.4 \pm 2.6) \sin 45 (t+1.6)$					
	SOM-II	$6.0 \pm 2.2 + (7.0 \pm 3.8) \sin 45 (t+16.2) + (15.5 \pm 3.5) \sin 30 (t+2.1) + (3.8 \pm 3.0) \sin 45 (t+1.9)$					
	I, II	$2.7 \pm 1.9 + (5.4 \pm 2.5) \sin 15 (t+17.4) + (14.6 \pm 3.0) \sin 30 (t+3.4) + (4.3 \pm 3.0) \sin 45 (t+1.7)$					
January	SOM-I	$6.2 \pm 1.8 + (2.5 \pm 2.2) \sin 15 (t+8.6) + (10.8 \pm 2.6) \sin 30 (t+4.6) + (4.4 \pm 3.5) \sin 45 (t+5.6)$					
	SOM-II	$11.8 \pm 2.1 + (5.1 \pm 2.8) \sin 15 (t+11.1) + (6.3 \pm 2.5) \sin 30 (t+2.4) + (0.9 \pm 2.9) \sin 45 (t+2.7)$					
	I, II	$9.4 \pm 1.8 + (2.9 \pm 2.3) \sin 15 (t+9.5) + (6.9 \pm 2.4) \sin 30 (t+3.0) + (5.6 \pm 3.3) \sin 45 (t+7.6)$					

* Commas represent decimal points.

TABLE 3 *

Month	Station	Type of equation					
October	SOM-I	$0.9 \pm 2.8 + (1.3 \pm 2.9) \sin 15 (t+7.2) + (21.3 \pm 4.0) \sin 30 (t+4.9) + (3.6 \pm 4.0) \sin 45 (t+6.3)$					
	SOM-II	$4.7 \pm 2.1 + (6.1 \pm 3.0) \sin 15 (t+22.9) + (17.4 \pm 3.8) \sin 30 (t+2.3) + (5.0 \pm 3.8) \sin 45 (t+1.9)$					
	I, II	$2.8 \pm 2.0 + (2.1 \pm 2.8) \sin 15 (t+0.4) + (6.3 \pm 3.1) \sin 30 (t+5.5) + (6.4 \pm 3.8) \sin 45 (t+4.0)$					
November	SOM-I	$-0.8 \pm 1.6 + (3.5 \pm 2.6) \sin 15 (t+19.2) + (14.8 \pm 3.6) \sin 30 (t+3.0) + (5.6 \pm 2.8) \sin 45 (t+1.6)$					
	SOM-II	$-3.8 \pm 1.9 + (3.6 \pm 2.6) \sin 15 (t+7.9) + (12.6 \pm 3.8) \sin 30 (t+1.8) + (10 \pm 5.0) \sin 45 (t+5.9)$					
	I, II	$-2.4 \pm 1.8 + (0.6 \pm 2.5) \sin 15 (t+23.0) + (12.1 \pm 3.3) \sin 30 (t+2.3) + (2.6 \pm 3.2) \sin 45 (t+1.5)$					
January	SOM-I	$7.8 \pm 2.0 + (10.7 \pm 4.8) \sin 15 (t+22.7) + (22.3 \pm 5.0) \sin 30 (t+3.8) + (9.8 \pm 4.5) \sin 45 (t+7.2)$					
	SOM-II	$11.8 \pm 1.9 + (5.1 \pm 3.9) \sin 15 (t+11.1) + (6.3 \pm 3.5) \sin 30 (t+2.4) + (0.9 \pm 4.0) \sin 45 (t+2.7)$					
	I, II	$9.8 \pm 1.8 + (2.6 \pm 3.6) \sin 15 (t+22.4) + (14.3 \pm 3.3) \sin 30 (t+3.7) + (4.3 \pm 3.6) \sin 45 (t+7.2)$					

* Commas represent decimal points.

The normalized correlation coefficient was calculated using the formula

$$r(T_k) = \frac{\sum_{i=1}^n n_{uv} u_i v_{i+k} - n \bar{u} \bar{v}}{\left[\left(\sum_{i=1}^n n_u u_i - n \bar{u} \right)^2 \left(\sum_{i=1}^n n_v v_i - n \bar{v} \right)^2 \right]^{1/2}},$$

where

n is the number of intervals in the days;

n_{uv} is the weight function;

$u_i v_{i+k}$ is the wind velocity correlating value for the i^{th} and $i+k^{\text{th}}$ intervals.

The scantiness of the sample led to a random, rather than a systematic, error in the statistical wind characteristic values. The root-mean-square error in the normalized correlation function attributable to this factor was estimated by using the formula /28

$$\sigma_r = \frac{1-r^2}{\sqrt{n-1}},$$

where

r is the correlation coefficient;

n is sample volume.

Analysis of the correlation curves reveals that the correlation coefficient falls to 0.7, on the average, with a shift in the correlation maximum of the order of one hour, when the separation in the working areas is 200 km in longitude. The correlation at coinciding times falls to 0.3, and the shift in the correlation maximum increases to 1.5 hours, when the separation between areas is increased to 500 km.

Figure 5a shows the decrease in wind measurement correlation with increase in separation between measurement areas.

Figure 5b shows the curve indicating an increase in the time shift to the correlation maximum with increase in separation between areas. The dashed line is the curve incorporating the correction for local time. The effect of a systematic lag in the 12-hour harmonic for the eastern region with respect to western of 1.5 hours when operating areas were 500 km apart was unexpected. The fixed phase position of the 12-hour harmonic for the /29

first radar consistently occurs earlier than for the second. The second radar was to the east of the first. Characteristic of all the correlation curves is the occurrence of the correlation maximum to the right (the ordinates of the second radar were fixed for the correlation function calculations, and the values of the ordinates of the first were shifted to the time increase side).

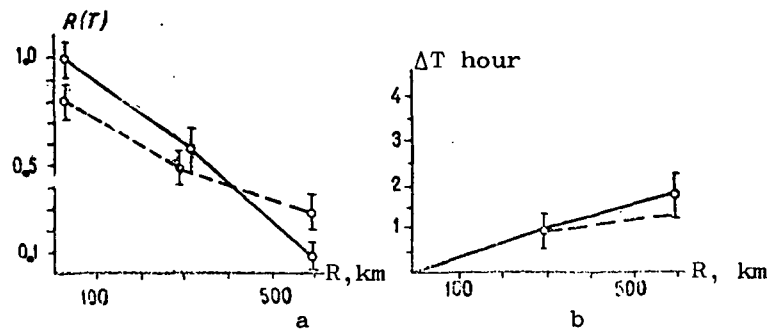


Figure 5. a - correlation of mean hourly wind velocities at two radars in terms of separation between areas; b - time shift to correlation maximum in terms of distance between sounded regions.

The phases of the 12-hour wind velocity oscillations at the first radar consistently led the corresponding phases at the second, as is evident from the above harmonic resolution equations.

The results indicate extraordinarily sharp longitudinal changes in regular wind parameter not previously noted. It is possible that the phase leads noted are among the effects associated with the existence of the hydrodynamic waves suggested by Hines [2] as being present in the E region of the ionosphere.

The experimental data obtained do not permit a final decision to be made with respect to whether these changes are wave, or random, in nature, or to what sort of spatial periodicity there is to the phase shifts noted. However, the results obtained indicate the incorrectness of the method conventionally used to measure mean velocity vectors by measuring the zonal and meridional components of one radar in different areas.

Simultaneous Measurement of the Zonal and Meridional
Components of the Wind Velocity Vector by Two Radars
In One Area

Observations made using Variant 4 (five measurement cycles were used in different months), and comparison of these data with results obtained using the generally accepted procedure, showed that the transition to one measurement area eliminated many previously observed, and difficult to explain, phenomena of the type that skew the axes of the polar diagrams characterizing the 12-hour changes in the velocity vector.

Table 4 lists, and Figure 6 shows, the equations for the mean curves for the harmonic resolution of the hourly histograms of wind velocities for conventional measurements (the results from one radar) and the measurements for one "local" area by the two radars from May to September 1965.

TABLE 4 *

Month	Radar and bearing	Type of equation
May	I	$53^\circ - 1,7 + 2,75 \sin 15 (t + 14,0) + 18,5 \sin 30 (t + 6,33) + 3,2 \sin 45 (t + 2,6)$
	II	$323^\circ + 4,4 + 11,6 \sin 15 (t + 3,86) + 8,7 \sin 30 (t + 3,56) + 6,7 \sin 45 (t + 0,76)$
June	I	$53^\circ - 0,8 + 9,6 \sin 15 (t + 20,9) + 24,8 \sin 30 (t + 7,27) + 7,1 \sin 45 (t + 4,97)$
	II	$323^\circ + 11,3 + 14,7 \sin 15 (t + 3,0) + 22,9 \sin 30 (t + 4,12) + 7,4 \sin 45 (t + 7,52)$
July	I	$53^\circ + 4,0 + 9,52 \sin 15 (t + 0,3) + 17,3 \sin 30 (t + 7,3) + 5,1 \sin 45 (t + 1,17)$
	II	$323^\circ + 13,5 + 9,96 \sin 15 (t + 1,3) + 17,94 \sin 30 (t + 1,22) + 6,5 \sin 45 (t + 4,6)$
August	I	$53^\circ + 4,0 + 10,7 \sin 15 (t + 22,7) + 11,09 \sin 30 (t + 7,28) + 8,7 \sin 45 (t + 5,47)$
	II	$323^\circ + 24,1 + 12,8 \sin 15 (t + 23,4) + 23,9 \sin 30 (t + 5,4) + 4,6 \sin 45 (t + 4,5)$
September	I	$53^\circ + 1,4 + 0,33 \sin 15 (t + 19,3) + 9,9 \sin 30 (t + 8,61) + 10,2 \sin 45 (t + 3,4)$
	II	$323^\circ + 1,1 + 1,92 \sin 15 (t + 10,9) + 12,9 \sin 30 (t + 4,58) + 5,63 \sin 45 (t + 4,12)$

* Commas represent decimal points.

Listed on line I are the mean hourly velocity histogram equations for the first radar when antenna orientation was northeast (azimuth 53°) and northwest (azimuth 323°). Listed on line II are the mean hourly wind velocity histogram equations for the second radar when antenna orientation was northwest (azimuth 323°). The initial measurements were of the "local" type when the antenna of the first radar was pointed to the northeast, and that of the second (located 200 km to the westward of the first) to the northwest. Antenna radiation pattern conditions were selected to illuminate a

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single meteor region in the atmosphere, and the angle between the mean hourly values of the horizontal components of the wind velocity was 90° .

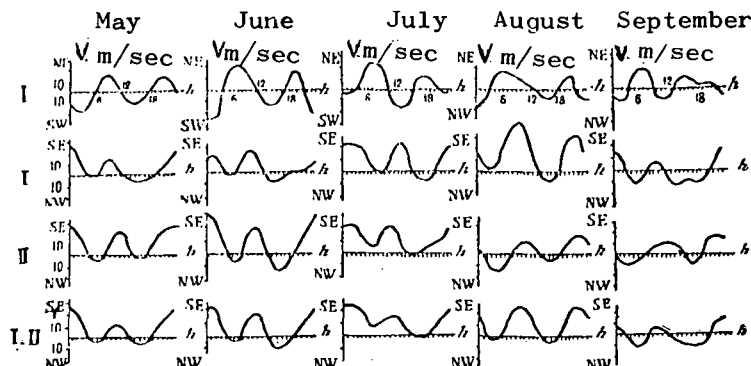


Figure 6. Histogram of drift velocities for the 4th (d) observation variant.

After three to five days of this type of measurements the antennas of the first radar were rotated 90° to the original bearing, and the second component of the wind velocity vector, which had been measured earlier by the second radar, was measured, but this time in an area 200 km away (measurements ceased at the second radar).

Figure 7 shows the polar diagrams of the 24-hour A_1 and the 12-hour A_2 harmonics.

The shift in phases between the north and west bearings differs substantially from 90° (3 hours) in the case of the 12-hour components for conventional measurements (series 1). Comparisons will show that in the majority of cases the major axes of the ellipses of the polar diagrams are oriented N-S and E-W when working the same area, despite the fact that the antennas were oriented NE and NW. The difference in phases between the north and east components, measured by two radars in the same area, was much closer to 3 hours for the 12-hour component than for the observations made by one radar.

The mean deviation of the major axes from north, for all months, based on "local" measurements, was $\Delta\phi = \pm 0.5$ hr, which agrees well with the mean error in the phase measurement for the 12-hour component. This mean deviation was $\Delta\alpha = \pm 1.5$ hr for conventional single-radar measurements.

The presence of some divergence in measured values of the prevailing

wind at two radars for measurements of the same component can be attributed to measurements having been made on noncoincident days.

The abrupt shifts in the prevailing wind from day to day (not associated with statistics) that we had previously noted made observations of the zonal and meridional components difficult on noncoincident days, so it is desirable to take measurements by switching the antennas to two azimuths, or to use two radar installations in a "local" variant and simultaneously measure two wind components.

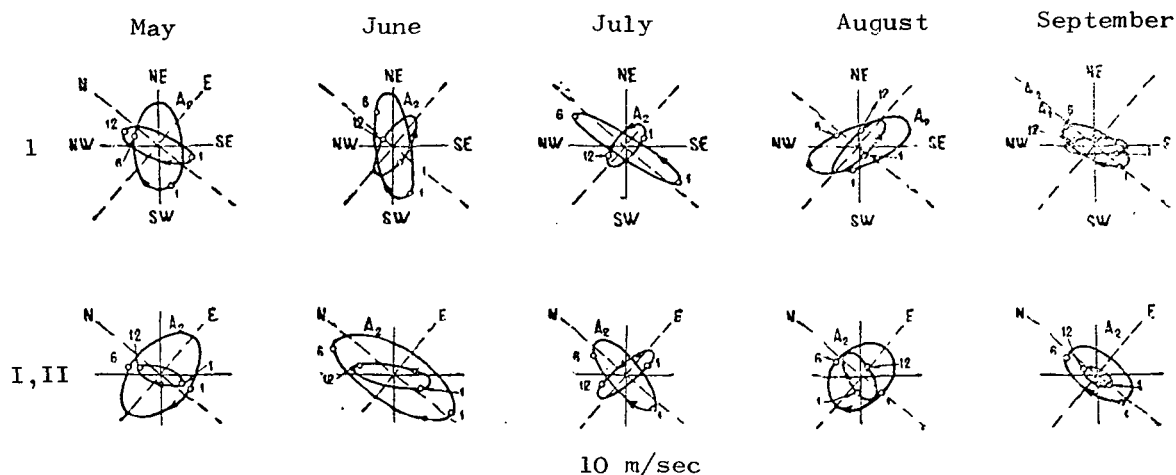


Figure 7. Polar diagrams of the 24-hour A_1 and 12-hour A_2 wind velocity component vectors for conventional (1) and two-radar (I, II) measurements.

REFERENCES

1. Karimov, K. A., Kostromin, V. D., Berezovskiy, M. I., "The Radar Installation for Observing Meteors in Kirghizia," Sb. Meteornoye rasprostraneniye radiovoln [In collection: Meteor Radio Wave Propagation], Part 3-4, Kazan', 1966.
2. Hines, C. O., "An Interpretation of Certain Ionospheric Motions in Terms of Atmospheric Waves," J. Geophys. Res., Vol. 64, No. 12, 1959.

ONE-DIMENSIONAL EXPANSION OF A METEOR TRAIL

N. A. Arkabayev

ABSTRACT. A mathematical analysis is made of the initial stage of expansion of hot vapors and gases in a meteor trail.

Study of the initial stage of the expansion of hot vapors and gases trailing a meteoric body is of considerable interest. /34

The earth's atmosphere is quite rarefied at altitudes of 80 - 100 km, as we know, and its density is between 10^{-8} and 10^{-9} g/cm³. Pressure is, for all practical purposes, zero.

Two approaches to the solution of problems of the discontinuum theory are possible: (1) using classical gas dynamics equations, and (2) using statistical physics methods.

The function defining particle density in phase space generally is taken from observations in applying statistical physics methods, so the solution is inexact.

We find it more desirable to use gas dynamics methods, including the interaction between the meteor and the atmospheric molecules surrounding it.

Let us consider the process of the expansion of the hot vapors and gases trailing a meteoric body, relative to the coordinate system associated with the body. In this system of coordinates, molecules vaporized from the meteoric body can be considered as molecules scattering from a cloud. And the mass of air in the trail has unit time momentum of

$$L = \Gamma \frac{S \rho'}{M} u^2, \quad (1)$$

where

Γ is the drag coefficient;

S is the area of the front section of the meteoric body;

ρ' is the atmospheric density;

M is the mass of the meteoric body;

u is the velocity of the meteoric body upon invasion into the atmosphere.

The increase in the mass of the air in the trail in unit time is equal to

$$b_1 = \lambda \frac{Sp'}{2M} u^3, \quad (2)$$

where

λ is the heat-transfer coefficient.

The drag coefficient, Γ , can be greater, or less, than unity at the same time that the heat-transfer coefficient, λ , always is less than (or equal to) unity.

The coefficients Γ and λ always are associated with each other in one way or another by physical processes which perform and accompany impulse and energy transfer.

Γ and λ are variables in the general cases, but the range of change is significantly less than the range of change in other magnitudes which determine the drag force and energy flow. Therefore, in the first approximation Γ and λ can be considered as constants.

The increase in the mass of the air in the trail in unit time, equated to a unit of mass of the meteoric body is equal to

$$b = \frac{b_1}{Q'} = \lambda \frac{Sp'}{2MQ'} u^3, \quad (3)$$

where

Q' is the energy necessary to heat and volatilize 1 gram of meteoric body material.

Let us consider the expansion of the trail as cylindrically symmetrical. The fundamental gas dynamic equations will, in the given case, then have the form

(1) impulse equation (Euler's)

$$\frac{\partial v}{\partial t} + v \frac{\partial v}{\partial r} = -\frac{1}{\rho} \frac{\partial P}{\partial r}, \quad (4)$$

where

v is the radial velocity component;

ρ is the trail density;

P is the trail pressure;

(2) continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial(v\rho)}{\partial r} + \frac{p v}{r} = b\rho, \quad (5)$$

(3) energy equation

$$c_v T \frac{d \ln \sigma}{dt} = b Q', \quad (6)$$

where

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$$\sigma = e^{\frac{s-s_0}{c_v}}, \quad (7)$$

s is the entropy per unit mass of the gas;

C_v is the specific heat of the gas for constant volume;

T is the trail temperature.

Let us take v , c , and ρ as dependent variables for convenience in subsequent calculations.

The equation of state for a polytropic gas

$$P = \sigma \rho^k, \quad (8)$$

where k is the polytropic index, leads to

$$\frac{dP}{\rho} = \left(\frac{\partial P}{\partial \rho} \right) d \ln \rho + \left(\frac{\partial P}{\partial \sigma} \right) \frac{d\sigma}{\rho} = c d \ln \rho + \frac{c d \ln \sigma}{k}.$$

Further, since

$$c = k \sigma \rho^{k-1},$$

then

$$d \ln \sigma = d \ln c - (k-1) d \ln \rho,$$

so

$$\frac{dP}{\rho} = \frac{1}{k} (dc + c d \ln \rho).$$

Because, in the case of a polytropic gas

$$dQ = c_v T d \ln \sigma = c_v T [d \ln c - (k-1) d \ln \rho],$$

Eq. (6), the conservation of energy equation, will have the form:

$$\frac{d \ln c}{dt} = (k-1) \frac{d \ln \rho}{dt} + \frac{1}{c_v T} b Q' \dots \quad (9)$$

From whence it follows that the basic set of equations for the variables, v , c , and ρ , can be written in the form

$$\left. \begin{aligned} \rho \left\{ \frac{\partial v}{\partial t} + v \frac{\partial v}{\partial r} + \frac{1}{k} \frac{\partial c}{\partial r} \right\} + \frac{c}{k} \frac{\partial \rho}{\partial r} &= 0, \\ \frac{\partial \rho}{\partial t} + v \frac{\partial \rho}{\partial r} + \rho \left(\frac{\partial v}{\partial r} + \frac{v}{r} \right) &= b \rho, \\ \frac{1}{k(k-1)} \left(\frac{\partial c}{\partial t} + v \frac{\partial c}{\partial r} \right) + \frac{c}{k} \left(\frac{\partial v}{\partial r} + \frac{v}{r} \right) &= b Q'. \end{aligned} \right\} \quad (10) \quad \underline{37}$$

Let us expand the solutions of these equations in a power series near the coordinate origin

$$\left. \begin{aligned} \rho &= \sum_{\lambda, \mu=0}^{\infty} \rho_{\lambda, \mu} r^{\lambda} t^{\mu}, \\ c &= \sum_{i, \kappa=0}^{\infty} c_{i, \kappa} r^i t^{\kappa}, \\ v &= \sum_{l, m=0}^{\infty} v_{l, m} r^l t^m. \end{aligned} \right\} \quad (11)$$

Substituting the proposed solutions of Eq. (11) into the Eq. (10) set, we obtain

$$\begin{aligned}
& \sum_{\alpha, \beta=0}^{\infty} \sum_{\lambda, \mu=0}^{\alpha, \beta} \{(\beta-\mu+1) \rho_{\lambda, \mu} v_{\alpha-\lambda, \beta-\mu+1} + \\
& + \sum_{i, \kappa=0}^{\lambda, \mu} (\lambda-i+1) v_{i, \kappa} \rho_{\alpha-\lambda, \beta-\mu} v_{\lambda-i+1, \mu-\kappa} + \frac{1}{k} [(\alpha-\lambda+ \\
& + 1) \rho_{\lambda, \mu} c_{\alpha-\lambda+1, \beta-\mu} + (\lambda+1) \rho_{\lambda+1, \mu} c_{\alpha-\lambda, \beta-\mu}] \} r^{\alpha} t^{\beta} = 0. \\
& \left(\sum_{\alpha, \beta=0}^{\infty} \{(\beta+1) \rho_{\alpha, \beta+1} + \sum_{\lambda, \mu=0}^{\alpha, \beta} [(\lambda+1) \rho_{\lambda+1, \mu} v_{\alpha-\lambda, \beta-\mu} + \right. \\
& \left. + (\alpha-\lambda+1) \rho_{\lambda, \mu} v_{\alpha-\lambda+1, \beta-\mu}] \} + \sum_{\alpha=-1, \beta=0}^{\infty} \sum_{\lambda, \mu=0}^{\alpha+1, \beta} \rho_{\lambda, \mu} \times \right. \\
& \left. \times v_{\alpha-\lambda+1, \beta-\mu} \right) r^{\alpha} t^{\beta} = b \sum_{\alpha, \beta=0}^{\infty} \rho_{\alpha, \beta} r^{\alpha} t^{\beta}. \quad \underline{38} \\
& \left(\sum_{\alpha, \beta=0}^{\infty} \left\{ \frac{\beta+1}{k(k+1)} c_{\alpha, \beta+1} + \right. \right. \\
& + \sum_{\lambda, \mu=0}^{\alpha, \beta} \left[\frac{\lambda+1}{k(k+1)} c_{\lambda+1, \mu} v_{\alpha-\lambda, \beta-\mu} + \frac{1}{k} c_{\lambda, \mu} \times \right. \\
& \left. \left. \times v_{\alpha-\lambda+1, \beta-\mu} \right] + \sum_{\alpha=-1, \beta=0}^{\infty} \sum_{\lambda, \mu=0}^{\alpha+1, \beta} c_{\lambda, \mu} v_{\alpha-\lambda+1, \beta-\mu} \right) r^{\alpha} t^{\beta} = bQ'.
\end{aligned}$$

We have transformed differential equations (10) into a system of algebraic equations defining the coefficients of the Eq. (11) series.

REFERENCES

1. Levin, B. Yu., Fizicheskaya teoriya meteorov i meteornoye veshchestvo v solnechnoy sisteme [Physical Theory of Meteors and Meteoric Material in the Solar System], "Nauka" Press, 1956.
2. Stanyukovich, K. P., Neustanovivshiyesya dvizheniya sploshnoy sredy [Nonsteady Motion of a Continuum]. Moscow, 1955.

MEAN MONTHLY CHARACTERISTICS OF THE WIND REGIME

K. A. Karimov, V. Ya. Ogurtsov, V. V. Sidorov

ABSTRACT. The mean characteristics of regular wind patterns were studied to ascertain the differences between true mean monthly values of wind characteristic parameters and the mean values obtained for 24-hours, or from methods used to average values for several days at a time.

The question of what is to be considered as the mean monthly drift is one of the most important such questions from the viewpoint of studying seasonal behavior patterns of the regular wind in the meteor region of the atmosphere. Drift measurements usually are made for an eight to ten day period, followed by measurements of the zonal and meridional components of the wind, in the third or fourth week of each month (this is the manner in which drift measurements were specified in the IQSY program).

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Averaged characteristics of the regular wind, obtained over an eight to ten day period, were taken as the mean monthly values. There is no arguing the fact that averaging such as this requires experimental verification. The problem of refining the procedure for obtaining mean monthly characteristics arose primarily because comparison of observation results obtained in different localities made it difficult to interpret results. This was because the measurements often were made on different days. Difficulties such as these obviously are associated with the fact that characteristics of the regular wind can vary greatly from day to day, as Greenhow [1] has noted.

The aim of our investigation was to ascertain the differences between the true mean monthly values of wind characteristic parameters and the mean values obtained for 24-hours, or by averaging over several days.

Results of the Experiment

Measurements of meteor trail drifts were made using a coherent pulse radar on a frequency of 39.5 MHz. Transmitter power was 50 kW, pulse repetition frequency was 100 pps, main pulse width was 10 μ sec, receiver sensitivity was $5 \cdot 10^{-14}$ W with the bandwidth 100 kHz. Reception and transmission was over a system of two cophased five-element antennas of

the "wave duct" type. The radar used is described in [2]. A continuous 30-day cycle of observation, from 3 January to 3 February 1966, was undertaken. The reliability of measurements by the first radar was monitored part of the time by the second radar complex. It should be pointed out that the results of simultaneous measurements of wind velocity by two diversity radars in one region of the atmosphere provide good daily correlation, as distinguished from what often is slight correlation between measurements made by one radar on successive days. /40

The results of the monthly measurements were broken down into four 5-7 day intervals:

- Interval I - from 3 to 9 January;
- Interval II - from 10 to 17 January;
- Interval III - from 17 to 24 January;
- Interval IV - from 24 January to 2 February.

The averaged characteristics of the regular wind were calculated using the harmonic expansion method for individual days, as well as for each of the four chosen intervals. The averaging of the results was done for the same hour, based on separate intervals, and for the month as a whole, computing a statistical weight for each mean monthly velocity. /41

Figure 1 shows the histograms for drifts by intervals, and Figure 2 shows the corresponding polar diagrams for variations in the vectors of the 24-hour and 12-hour harmonics.

Table 1 lists the corresponding harmonic expansion equations for the meridional and zonal components of the 24-hour histograms for drift velocities. The first row gives the drift velocity equation for one day (16 January) for comparison purposes. The rows with indices I, II, III, IV, show the histogram equations for the corresponding averaging intervals, and the last row, with index (M), lists the equation for the true mean monthly histogram. The mean errors in the expansion components also were analyzed, and were equal to:

1. for the constant term $\sigma A_0 < 2.0$ m/sec;
2. for the amplitude of the first harmonic $\sigma A_1 = 3.3$ m/sec; for the phase $\sigma \varphi_1 = 25^\circ - 30^\circ$;

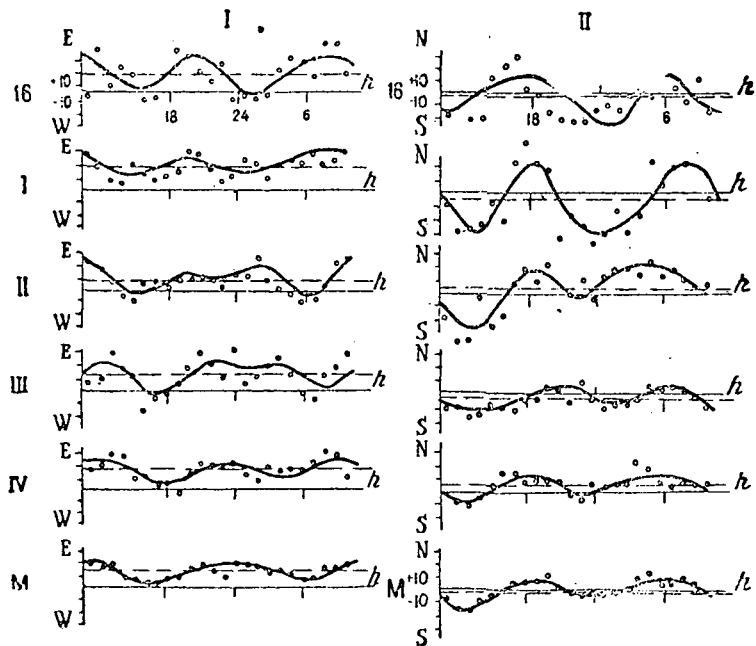


Figure 1. Histograms of drifts for a 24-hour period (16), for the intervals (I, II, III, IV), and the mean monthly histogram (M) for the monthly observation cycle.

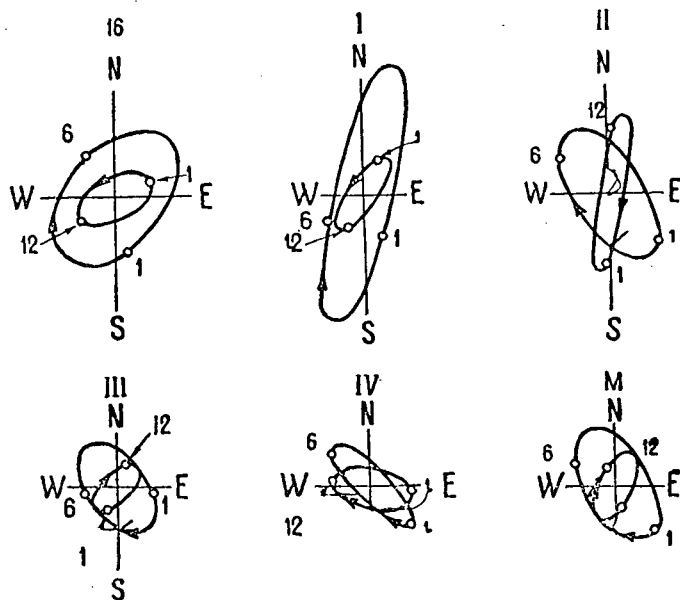


Figure 2. Polar diagrams of the vectors of the 24-hour (A_1) and the 12-hour (A_2) components for a 24-hour period (16), for the intervals (I, II, III, IV), and the mean monthly diagram (M).

TABLE 1 *

Direction	Averaging interval	Type of equation
E-W	16 January	$15,2 + 7,2 \sin 15 (t + 7,1) + 12,9 \sin 30 (t + 4,9) + 8,6 \sin 45 (t + 6,7)$
	I	$21,0 + 3,6 \sin 15 (t + 7,8) + 6,2 \sin 30 (t + 4,4) + 2,6 \sin 45 (t + 0,5)$
	II	$8,4 + 1,4 \sin 15 (t + 10,3) + 9,2 \sin 30 (t + 2,2) + 11,2 \sin 45 (t + 1,7)$
	III	$13,5 + 5,2 \sin 15 (t + 13,2) + 9,7 \sin 30 (t + 1,6) + 8,2 \sin 45 (t + 7,7)$
	IV	$17,1 + 6,1 \sin 15 (t + 7,7) + 6,3 \sin 30 (t + 1,9) + 1,6 \sin 45 (t + 6,8)$
	M	$14,0 + 3,0 \sin 15 (t + 14,0) + 6,1 \sin 30 (t + 2,0) + 3,2 \sin 45 (t + 0,5)$
N-S	16 January	$-5,9 + 6,1 \sin 15 (t + 4,3) + 16,4 \sin 30 (t + 7,9) + 7,6 \sin 45 (t + 3,3)$
	I	$-6,0 + 9,3 \sin 15 (t + 4,9) + 32,3 \sin 30 (t + 5,6) + 9,8 \sin 45 (t + 2,6)$
	II	$2,9 + 18,4 \sin 15 (t + 15,0) + 15,5 \sin 30 (t + 6,7) + 7,3 \sin 45 (t + 1,2)$
	III	$-6,0 + 5,9 \sin 15 (t + 14,0) + 7,9 \sin 30 (t + 5,1) + 3,7 \sin 45 (t + 5,4)$
	IV	$4,1 + 4,0 \sin 15 (t + 14,3) + 8,1 \sin 30 (t + 6,9) + 2,5 \sin 45 (t + 2,1)$
	M	$-0,2 + 5,2 \sin 15 (t + 13,5) + 10,0 \sin 30 (t + 6,6) + 1,6 \sin 45 (t + 2,9)$

* Commas represent decimal points.

3. for the amplitude of the second harmonic $\sigma A_2 = 3.5$ m/sec; /43
for the phase $\sigma \varphi_2 = 15^\circ$;

4. for the amplitude of the third harmonic $\sigma A_3 = 3.3$ m/sec;
for the phase $\sigma \varphi_3 = 35^\circ$.

The deviations in the 24-hour, and especially in the 12-hour amplitudes, measured on individual days, from the mean monthly values were substantially greater than the measurement errors. It must be noted that averaging a great many days results in a relative reduction in the amplitude of the 12-hour harmonic by a factor of 1.3 to 1.5 as compared to the results for single days. An analysis of phase relationships for zonal and meridional components shows that characteristic of the 12-hour component for the month is clockwise rotation. There were virtually no changes in the phases of the harmonic expansion components in the monthly observation cycle. It can, therefore, be recommended that the phases of the harmonic expansion components be analyzed for a year, by days (excluding the spring and fall months).

Deviations in the prevailing wind, by days and by intervals, from the monthly mean are of particular interest.

Velocity Behavior of the Prevailing Wind

The majority of the deviations in the prevailing wind from the true mean monthly value exceed the measurement errors by a factor of from 2 to 3 (interval III was an exception).

Figure 3 shows the values of the prevailing wind for each day in January for the meridional and zonal components.

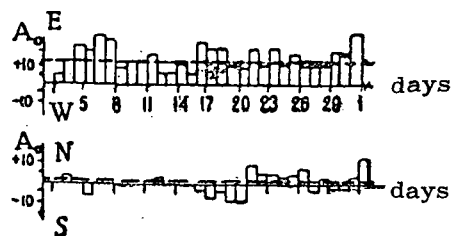


Figure 3. Mean values of the prevailing wind, A_0 , by days in January.

There were substantial deviations in the prevailing wind on a day-to-day basis during the month, going well beyond the limits of measurement errors. These obviously were not due to instrument effect, but were associated with chaotic fluctuations in the prevailing wind from day to day.

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Figure 4 is the vector diagram of the variations in the prevailing wind, A_0 , from 16 to 31 January, and can be used to follow the periodicity in the variations in the A_0 vector. The X is the mean monthly value of the prevailing wind vector. Muller notes a similar periodicity, one with a period of from 3 to 9 days [3].

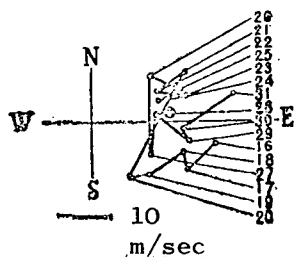


Figure 4. Vector diagram of variations in A_0 , between 16 and 31 January. X - the mean monthly position of the A_0 vector.

Figure 5 shows the autocorrelation function of deviations in the daily ΔA_0 values for zonal components of the velocity of the prevailing wind from the monthly mean with measurement errors.

The autocorrelation function, the value of which was calculated for the mean daily deviation for 29 days, has a periodic component with a period of 9 to 11 days, and an amplitude commensurate with the 12-hour harmonic. A shift of one day will result in a decrease in the correlation coefficient to the magnitude of the periodic component. Evidently, even if there are random jumps, they occur during a time interval of less than one day and appear as random oscillations in the

amplitudes and phases of the 24-hour harmonics. A more detailed analysis of the correlation bonds between fluctuations A_0 was made by constructing an autocorrelation function for deviations in mean hourly velocities for each day from the smoothed curve of means for six days of observations, obtained by harmonic expansion, including three periodic harmonics.

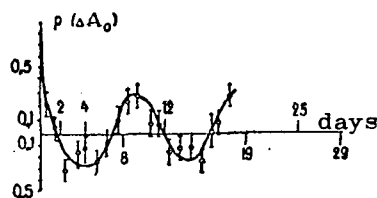


Figure 5. Autocorrelation function of daily deviations in the ΔA_0 value from the monthly mean (for the zonal component of the prevailing wind).

Slow variations in A_0 during this period of observation also were included. Thus, we attempted to separate possible fluctuations in wind velocity from well-studied regular variations. Figure 6 is the autocorrelation function of random hourly deviations obtained during six days of continuous observations, together with errors in the determination of the correlation coefficient.

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The clear correlation of fluctuations in intervals of less than 24-hours is evident. This agrees with the preceding conclusions (see Figure 5).

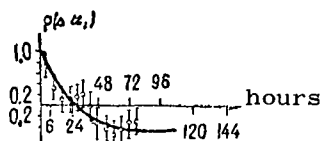


Figure 6. Autocorrelation function of random hourly deviations during six days of continuous observations.

The consolidation of the results of several days of observations is important primarily as a means of obtaining the mean monthly characteristics, including possible and irregular many-day variations in wind characteristics.

The 9 to 11 day oscillations in the prevailing wind that we noted can

serve as an additional argument in favor of the incorrectness of taking measurements of meridional and zonal wind components on days that do not coincide. Everything said leads to the recommendation that the following organization of the service be used to study seasonal behavior patterns: measurements to be taken 4 or 5 times a month, with 1-1/2 days in each interval (a two day and one night, interval), with observations distributed uniformly over the whole monthly cycle. This organization of the observations will permit following variations in A_0 during the month, season, and

year, and make possible an attempt to establish a correlation with the variables in the lower layers of the atmosphere.

All of which poses for the experimenters the problem of using more detailed investigations of 24-hour variations in the prevailing wind to develop a statistically more correct method of determining the mean monthly parameters of the regular wind.

REFERENCES

1. Greenhow, J. S., Neufeld, E. L., "Winds in the Upper Atmosphere," Royal Meteorological Society, Greenwich, Vol. 87, 1961, 374. /46
2. Karimov, K. A., Kostromin, V. D., Berezovskiy, M. I., "The Radar Installation for Observing Meteors in Kirghizia," Sb.: Meteornoye rasprostraneniye radiovoln, [In collection: Meteor Propagation of Radio Waves], Parts 3-4, Kazan', 1966.
3. Muller, H. G., "Atmospheric Tides in the Meteor Zone," Planetary and Space Science, Greenwich, 14, No. 12, 1966.

A RADAR VARIANT FOR A METEORIC WIND PATROL

K. A. Karimov, V. D. Kostromin, V. Ya. Ogurtsov

ABSTRACT. The development of the SOM-III radar is described.

References [1-5] have reviewed the basic requirements for radar designed to investigate the physics of a meteor trail, and to study the physical characteristics of the upper atmosphere.

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The parameters of a radar with a master oscillator, as well as with a self-excited oscillator, had been discussed previously, and had been included in the decisions made by the Commission of the Interdepartmental Geophysical Committee of the Presidium of the Academy of Sciences of the USSR in April-June 1962.

The recommended principal characteristics of radars were: wavelengths $\lambda = 8$ m; pulse power $P_p = 100$ kW; pulse width $\tau \geq 10$ μ sec; repetition frequency $F_r \geq 200$ pps; antennas with a gain of $G \approx 15-20$; receiver with an optimum bandwidth $\Delta f = 1/\tau$ and response $\alpha \approx 10^{-13} - 10^{-14}$ W.

The authors adhered to these basic requirements during the development of complex measuring equipment, the result of which was the SOM-III radar. This paper is devoted to the justification and selection of the block diagram for a meteoric wind patrol radar.

The SOM-III radar was developed to study the density of meteor material radiant points in the celestial hemisphere and atmospheric circulation.

The selection and development of the block diagram for a radar to record the following parameters of a meteor echo proceeded from a concretely formulated task that included:

- (a) frequency and time of appearance of the echo;
- (b) meteor echo range determination;
- (c) measurement of angles of arrival from a reflecting point by the amplitude method with antennas set up at different heights;
- (d) measurement of Doppler frequencies by phase-time and sector recording methods;

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(e) measurement of the apparent geocentric velocities of meteor entry.

Measurements of all parameters cited were to be made on different azimuths within a 2π limit using a "pulsed" antenna.

Threshold signal power can be increased by increasing the radiated wavelength ($P_{th} \sim \lambda^3$), given a maximum self-excited oscillator power of $P_p \approx 45-55$ kW and a receiver response limited by antenna noise of $\alpha = 5 \cdot 10^{-14}$ W. The selection of the wavelength for the SOM-III radar therefore was taken as 10 meters (further increase in λ will result in the reflection of radio waves from ionospheric inhomogeneities). Receiver bandwidth was selected as optimum at $\Delta f \leq 1/\tau$ ($\tau \leq 10$ msec). The noise voltage was taken as $\bar{u}_n \approx (4kTR\Delta f)^{1/2}$ (when $\Delta f = 80-100$ kHz, $\bar{u}_n \approx 4$ μ V).

These factors became the basis for the selection of the following principal parameters for the optimum variant of a meteor radar: wavelength $\lambda \approx 10$ meters; pulse power $P_p = 45-55$ kW; pulse width $\tau = 10$ μ sec; repetition frequency $F_r = 50-100$ pps; receiver sensitivity $\alpha = 5 \cdot 10^{-14}$ W when $\Delta f \approx 60-100$ kHz; five-element "wave duct" antenna with gain $G = 20$.

Description of the SOM-III Block Diagram

The radar transmitter and receiver are installed in the same van. The antenna array, consisting of two in-phase fed antennas in each stage, is mounted on the van. The van can rotate as a unit in accordance with a specified program. Figure 1 is the block diagram of the SOM-III radar.

The transmitter, 7, operates in the self-excited oscillator mode with push-pull plate modulation. The radiated frequency is stabilized by quarter-wave cavity resonators connected to the tube cathodes.

The trigger, 8, ensures synchronous operation of the radar as a whole and transmitter modulator triggering as well. One of two frequencies, $F_r = 50-100$ pps, can trigger the radar. All three trigger frequencies are phased with respect to high-voltage rectifier pulsations supplied to the transmitter modulator and ensuring the stability of the amplitude of the radiated pulses.

The frequency repetition switch, 9, generates a higher pulse repetition frequency to trigger the transmitter, 7, and is cut in with the arrival of

a useful signal from the selector, 6. The pulses generated by the repetition frequency switch are mixed into the main series of trigger pulses in the synchronizer, 8. The transmitter in this case is operated in the boost mode for a short period of time. This unit is necessary to measure the apparent geocentric velocities of meteors. One additional main pulse, needed to determine the direction of the drift during sector recording, is generated when key K_1 is switched to the AMP (additional main pulse) unit, 18.

The receiver has two channels, a main, 2, and an auxiliary, 1. The auxiliary channel is used to measure the angles of arrival of a reflecting point by the amplitude comparison method at two antennas with different heights.

Signals received by the antennas are amplified in the high-frequency stages, 1 and 2, and are fed to the receiver, 5, through a switching gate, 3, assembled in a conventional circuit. An electronic key, 4, switches the switching gate. The main synchronizer, 8, synchronizes switching.

The receiver, 5, is a conventional superheterodyne circuit with dual frequency conversion and an output intermediate frequency of 2.0 MHz.

Signals flow from the receiver to the selector, 6, where signals are selected out of the noise by duration of reflected signal, amplitude of threshold level, and by the synchronism of the radar's pulsing. Selector 6 generates sensitizing pulses which are fed to the modulators of all indicators.

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Signals are fed to the amplitude indicator, 12, from receiver 5 after detection and a 3-4 μ sec delay. The linearity of the reception channel is such that the signal is stronger than the noise by a factor of 15 to 20.

A range indicator, 15, is used to record the slant range. A synchronized pulse from selector 6 is supplied to the range indicator, where it is seen as a pair of points. Sweep length corresponds to range from 100 to 500 km. Range markers, 20 km apart, are provided to measure range.

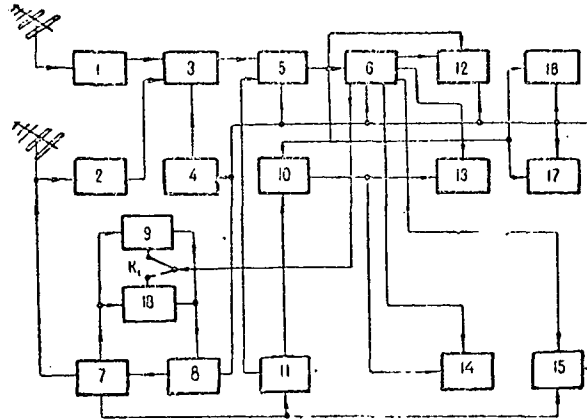


Figure 1. Block diagram of the SOM-III radar.

The oscillations of a pseudocoherent beat-frequency oscillator, generated in the phase synchronization unit, 11, are used to isolate the Doppler beat from the reflected signal frequency and the original frequency generated by the self-excited oscillator. The reference frequency is formed during phase synchronization of the oscillations of the high-frequency oscillator operating in the pulse mode and the oscillations of a special coherent beat-frequency oscillator. Phase synchronization of the pseudocoherent beat-frequency oscillator is by sync pulses from the transmitter flowing through the receiving channel at the intermediate frequency $f_i = 20$ MHz. Coherence is retained within one repetition period for intervals between transmitter pulses of 5 to 10 msec.

Phase detector 10, a symmetrical sum-difference circuit with a bridge rectifier suitable for pulse work, is used to isolate the beat voltage from the reference oscillator and the reflected echo signal. A two-channel phase detector is used to determine the trace displacement sign. A phase shifter supplies the signal to the second channel with a 90° shift in phase. The coherence of the reference oscillator and the phase shift between the two channels in the detector is monitored at the phase detector output by the echo signal from the mountains [6].

Two indicators, one a phase-time, the other a "sector display," are used to record the meteor trail drift. Use of two indicators makes it

possible to study temporal changes in the drift rate. The signal flow is from the discriminator, 10, to the phase-time indicator, 13, which records reflected echoes with duration $\tau_e > T_g$ (the Doppler period).

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The same signal flows from discriminator 10 to the "sector display" indicator, 14, which records the reflected echoes with duration τ_e shorter than the Doppler period T_g .

A reflected signal power monitor unit, 17, is used to monitor the stabilization of the operation of transmitter 7, and of the receiving channel. This is done by gating the signal from the mountains, converting it into direct current, and continuously recording this voltage on a type N-370M recorder. This reflected signal power measuring device monitors the transmitter's radiated amplitude, as well as the stability of the receiving channel.

Noise is recorded by device 16 continuously in order to study cosmic noise, which fluctuates over the 24-hour period, and permits monitoring the signal/noise ratio.

Transmitter Frequency Repetition Switch

Figure 2 is the block diagram of the frequency repetition switch for triggering the transmitter. The master repetition frequency for triggering the transmitter is 100 pps. A higher repetition frequency, 400-700 pps, is needed to determine meteor velocity from the diffraction pattern. A circuit that switches transmitter operation to a high-power mode is used because there is no way to obtain more than 40 kW from the type GI-1 tubes used in this particular transmitter when repetition frequency is increased.

Signals flow from the receiver, 1, to the selector, 2. A signal satisfying selection conditions is fed into the resolver, 3, which generates a 0.1 second pulse, during which time high-frequency repetition pulses are supplied to the synchronizer from the increased repetition frequency unit, 4, which operates continuously, to trigger the modulator in the transmitter, 5.

Use of an increased repetition frequency causes a drop in pulse power, but as the experiment showed, when operation is in the boost mode with $t = 0.1$ second, the power drop is slight.

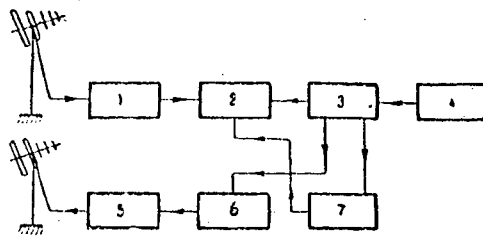


Figure 2. Block diagram of the repetition frequency switch for triggering the transmitter.

Time relay 7 is triggered when the increased frequency unit is cut in, opening the signal circuit from selector 2. Relay operating time can be adjusted from 0.5 second to several tens of seconds. This was incorporated to preclude repeat sounding of the same trail.

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The following expression can be used to find the meteor velocity from its diffraction pattern

$$V_g = \frac{t}{2} F_r \frac{\sqrt{R\lambda}}{N}, \quad (1)$$

where

V_g is the apparent meteor velocity;

t is the time interval between the diffraction echo maximum and minimum;

N is the number of pulses between maximum and minimum;

F_r is the radar's repetition frequency.

The mean probable velocity of meteors is 40 km/sec, so the repetition frequency, F_r , should be at least 500 pps.

Angle Measurement Device

The angle measurement device is used to determine the altitudes of the reflecting points on a meteor trail. One of the simplest of the methods used to determine the bearing of a target, the amplitude method, which uses the directional properties of antennas, can be used to measure

the angles of arrival of a reflected signal. Target direction finding is by the comparison of two amplitudes. The signal voltages at antennas h_1 and h_2 can be represented in the form

$$\begin{aligned} U_{h_1} &= U_0 f_1(\alpha), \\ U_{h_2} &= U_0 f_2(\alpha), \end{aligned} \quad (2)$$

where

$f_1(\alpha)$ and $f_2(\alpha)$ are the direction-finding characteristics of the antennas.

The ratio of the amplitudes of two incoming signals, U_{h_1} and U_{h_2} , are proportional

$$\frac{U_{h_1}}{U_{h_2}} = \frac{f_1(\alpha)}{f_2(\alpha)}. \quad (3)$$

The azimuth, α , to the reflecting target [7], can be determined on the indicator by measuring the reflected signal amplitude from two antennas.

Antenna heights are $h_1 = \lambda/2$ and $h_2 = 3/4 \lambda$. The radiated power maximum occurs at $\Theta = 30^\circ$ and $\Theta = 49^\circ$.

The signals from the antennas are amplified in two high-frequency stages, 1 and 2, and are fed into the main receivers, 5, through electronic switch 3, controlled by key 4, passing the antenna pulses according to the clock time, and then on into the recorder (see Figure 1).

Sector Recording of Doppler Frequencies

Use of sector recording increases the number of meteor echoes processed [4, 8]. When the phase-time method is used, 25 to 30 percent of the radio echoes are not processed because the radio echo reflection time is less than the Doppler period, because of underdense trails. Combining the phase-time and "sector display" recording methods makes it possible to process 80 percent of all radio echoes received. It is difficult to determine the direction in which the meteor trail is drifting because of the low frequency of the radar's transmissions when sector recording is used. In our case, we determined the direction of drift by using an additional main pulse, an AMP.

A sync pulse is supplied to the AMP unit, 18, from the transmitter, 7. The AMP unit forms a pulse for additionally triggering the transmitter modulator, the TTM pulse, which is mixed with the main series of sync pulses in unit 8. TTM pulse passage is enabled in the selector, 6, as a result of the signal reflected from the meteor. After pulse passage is enabled, the TTM pulse is fed into the master oscillator, 8, mixed with the main series of pulses, and fed into the transmitter modulator forming the AMP (see Figure 1).

The AMP appears on the right, or left, of the transmitter's main pulse, depending on direction of meteor trail drift. The AMP circuit is reviewed in more detail in reference [8].

Cosmic Noise, Receiver Response, and Transmitter Power Measuring Device

Figure 3 is a block diagram of the noise and reflected signal power measuring device. The gating stage, 1, is triggered by a pulse from the transmitter modulator and is used to separate signals with different ranges.

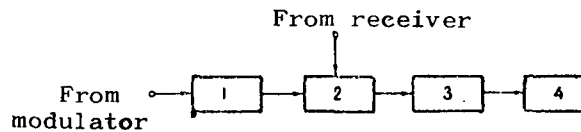


Figure 3. Block diagram of the noise and power monitor measuring device.

Displacing the gate, we can record (a) the amplitude of the main pulse controlling transmitter power, (b) the amplitude of pulses reflected from the mountains and controlling transmitter power and the response of the receiving channel simultaneously, and (c) we can measure cosmic noise. Receiver signals flow into amplifier 2, where high-frequency amplification takes place, the signals are detected, video frequency amplification takes place, and the signals then are fed into converter 3 which converts the pulse voltage into direct current voltage. The direct current voltage magnitude depends linearly on the magnitude of the pulse voltage. The direct current voltage is amplified and fed into the type N-370M recorder, 4.

The measuring device thus can monitor the receiver response and transmitter power, and can measure cosmic noise in accordance with a specified program. The results obtained from recording noise and reflected signal power can be used to make more precise corrections to the data on the daily density of the radiant points, and to study the amplitude characteristics of meteor echoes.

REFERENCES

1. Kostylev, K. V., "Equipment at the Engel'gard Astronomical Observatory for Radar Observation of Meteors with Automatic Recording," Astronomicheskii zhurnal, Vol. 35, No. 634, 1958. /55
2. Fialko, Ye. I., Problemy radiolokatsii meteorov [Problems of Radar Observations of Meteors], Tomsk Institute of Radioelectronics Press, 1961.
3. Kashcheyev, B. L., Dudnik, B. Ye., Lysenko, I. A., Lagutin, N. F., "Equipment for Radar Observations of Meteors," Sb.: Meteory [In collection: Meteors], No. 1, Kharkov, 1960.
4. Sidorov, V. V., Radiometeornyye metody i apparatura dlya nablyudeniya dvizheniya v verkhney atmosfere [Radio Meteor Methods and Equipment for Observations of Motion in the Upper Atmosphere], Thesis, Kazan', 1963.
5. Nemirova, E. K., Peregudov, F. I., "The TPI-1 Radar for Studying Meteor Trails," Tr. Sib. fiz.-tekhn. in-ta [Proceedings of the Siberian Physics and Technical Institute], Vol. 37, 1959.
6. Karimov, K. A., Kostromin, V. D., Berezovskiy, M. N., "A Radar Installation for Observing Meteors in Kirghizia," Sb.: Meteornoye rasprostraneniye radiovoln [In collection: Meteor Propagation of Radio Waves], No. 3, 4, Kazan', 1966.
7. Saybel', A. G., Osnovy radiolokatsii [Radar Fundamentals], "Sov. radio" Press, 1961.
8. Karimov, K. A., Ogurtsov, V. Ya., "Sector Recording of Meteor Trail Drifts in the Case of Low Frequency Radar Transmissions," [In this collection].

SECTOR RADIO MEASUREMENTS OF METEOR TRAIL DRIFTS BY LOW FREQUENCY RADAR TRANSMISSIONS

K. A. Karimov, V. Ya. Ogurtsov

ABSTRACT. The use of the "sector" method to record meteor trail drifts by radars using a sampling rate of $F_r = 100-200$ pps is described.

The results of observations of meteor trail drifts by radio methods are very much dependent on the number of recorded meteor reflections from which the Doppler frequency shift can be measured [1]. /56

In 1953, L. A. Manning [2], in a variant of continuous radiation, used the vector method of indicating meteor echoes, so that short reflections ($\tau_e = 0.02 - 0.05$ sec) could be used for Doppler measurements.

Later, in 1957, V. V. Sidorov [3] performed vector recording of the phase characteristics of reflected signals in a pulse variant.

This article describes the use of the "sector" method of recording meteor trail drifts at radars with a sampling rate of $F_r = 100-200$ pps.

The "Sector" Recording Method

The results of meteor trail drift observations in the IQSY period after 1964 at the SOM-1 meteor radar (Frunze) were processed and showed that a significant part (25-30%) of all recorded meteor echoes are brief specular reflections. The duration of these reflections is less than one Doppler period ($\tau_e < T_g$), so it is impossible to determine wind characteristics of such echoes by the phase-time method.

A direct count of the experimental material, obtained by the phase-time method, showed that the relative number of useful reflections is equal to 0.60. This result agrees well with that obtained in reference [3].

The expression for the ratio between the number of useful reflections and the total number of reflections has the form

$$\frac{N_u}{N_t} = \int_0^{\infty} P(t) \cdot F(t) dt, \quad (1) \quad /57$$

where

$P(t)dt$ is the probability that the duration of the meteor reflection, τ_e , is in the limits from t to $t + dt$;

$F(t)$ is the probability that $T_g \leq t$.

Integrating Eq. (1) yields $N_u/N_t = 0.56$.

Therefore, only 56-60% of all the meteor reflections recorded by the phase-time method yields to processing.

The relative number of useful reflections does not depend on recording time t_r for meteor reflections with $\tau_e > T_g$. Line a in Figure 1 shows the relative number of useful reflections in terms of recording time.

The following formula was used to find the relative number of useful reflections in the case of the sector recording method

$$\frac{N_u}{N_t} = [1 - F(\tau_e \leq t_r)] [F(T_g \leq t_c) - F(T_g \leq t_r)], \quad (2)$$

where

$$t_c = \frac{2\pi t_r}{m\delta\theta};$$

$\delta\theta$ is the mean error in determining the position of the drift velocity vector;

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m is a parameter chosen because of the requirement for measurement accuracy, but less than 2π ;

$F(T_g)$ is the integral distribution of the Doppler periods;

$F(\tau_e)$ is the integral distribution of meteor reflection durations.

As is evident from Eq. (2), the relative number of useful reflections depends on recording time, t_r . Hence, the usefulness of each meteor will be determined by the probability that the time of its existence will be longer than the recording time ($\tau_e > t_r$), but not longer than the Doppler period ($\tau_e > T_g$), as is the case for phase-time recording.

Taking these experimental data as the original data, and using Eq. (2), we obtain a graph for relative number of useful reflections in terms of

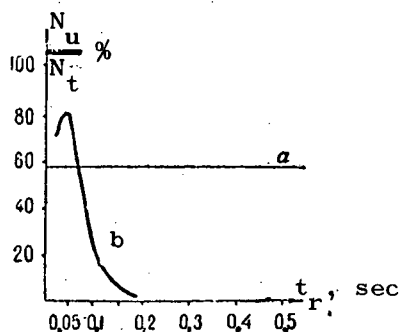


Figure 1. Number of useful reflections in terms of recording time.

recording time (curve b in Figure 1).

The "sector" method provides a gain of 25% in the number of measured Doppler echoes when recording time is $t_r = 0.04$ sec.

Thus, changing from the phase-time to the "sector" recording method provides an increase in the number of useful reflections from 56% to 80%.

It is known [4] that $N \sim P^{1/2}$, so such an increase in the number of measured echoes is extremely significant for comparatively low power (of the order of 40-60 kW) wind radars.

Selection of Number of Pulses for Determining the Phase Vector Angle of Rotation

The minimum number of "illuminating" pulses, sufficient for an accurate determination of the phase vector angle of rotation, $\Theta(t)$, can be determined from the well-known expression

$$t_r \geq \frac{n_{\min}}{F_r}, \quad (3)$$

where

$n_{\min}$ is the minimum number of "illuminating" pulses;

F_r is the sampling rate for the radar.

The recording time selection should satisfy the condition of providing the necessary overlap of possible Doppler period values for the largest number of recorded useful echoes.

The experimental data obtained by the SOM-1 meteor radar (Frunze) were used to construct a Doppler period distribution curve. This curve (Figure 2) shows that the most probable Doppler period values are in the limits of $0.03 \leq T_g \leq 0.26$ sec. Limiting the angle of rotation for the reflected vector to $\pi/3 \leq \Theta(t) \leq 7\pi/4$, we can establish that optimum recording time is $t_r = 0.045$ sec from the formula

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$$\Theta(t) = \frac{2\pi t_r}{T_g}. \quad (4)$$

Curve b (Figure 1) makes it apparent that the number of useful reflections is very critical in recording time selection. The maximum number of useful reflections is obtained when the recording time is $t_r = 0.04 - 0.05$ sec.

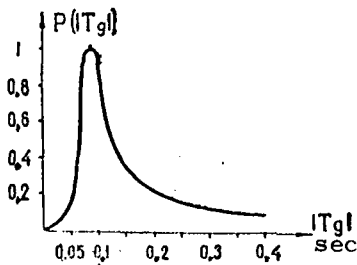


Figure 2. Doppler period distribution.

The use of a radar sampling rate of from 50 to 200 pps [5, 6] is necessary, and sufficient, for measuring wind in the upper layers of the atmosphere from meteor trail drift observations.

The minimum number of "illuminating" pulses for specified recording times and sampling rates can be found by using Eq. (3).

Table 1 leads to the conclusion that four "illuminating" pulses are quite sufficient for establishing the angle of rotation, $\Theta(t)$, characterizing the radial component of the meteor trail drift rate when $F_r = 100$ pps.

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TABLE 1

F, pps	50	100	150	200
n, min	2	4	6	8

Determination of the Direction of Meteor Trail Drift in Space

Determination of the direction of meteor trail drift in space is highly important in processing Doppler velocities.

The evaluation of the sign for rotation of the reflected vector as "toward" or "away" was made in earlier work with equipment with sector recording by the increase in the brightness of the initial intensification, or by a break in the initial section of the series of intensifier pulses.

The major deficiency in the first method is the effects of film development. The second method is suitable only for radars with high

sampling rates.

We had four intensifier pulses, so we introduced an additional main pulse, an AMP, to provide reliable determination of the direction of meteor trail drift. The sign of reflected vector rotation can be evaluated from the position of the additional main pulse, whether it is to the right, or left, of the reference pulse.

Additional Main Pulse Block Diagram

The additional main pulse unit determines the direction of the meteor trail drift in space. The functional diagram is shown in Figure 3.

The main pulse is fed from the transmitter to stretcher 1. The width of the pulse from the stretcher should be such that the AMP is not contained in the meteor recording working zone with respect to the "time window" range. The radar "window" usually is established during observations such that the signal receiver is unblocked from the moment in time corresponding to the arrival of reflections from a distance of 100 km, and is blocked for distances greater than 500 km. In this connection, the stretcher shapes a 7-8 msec pulse.

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The pulse flows through differentiating circuit 2, and gating stage 3 is triggered by the trailing edge, generating a 20-30 msec pulse that triggers the transmitter keyer. This pulse will be called the TKT pulse in what follows. The TKT pulse flows from gating stage 3 to passage enabling stage 6.

The enabling stage operates in the following manner. A radio echo reflected from a meteor trail is duration and amplitude selected and flows from amplitude discriminator 11 to shaping stage 10. The shaping stage generates a 15-20 μ sec signal which is supplied to the stage that shapes the pulse that enables TKT passage. The width of the TKT passage enabling pulse is 7-8 msec.

No command signal is generated when no radio echo is reflected from a meteor trail, the plate of gating stage 3 is shunted by the diode, and the amplitude of the TKT pulse becomes too small to trigger the threshold circuit 5. Presence of a TKT passage enabling pulse prevents the plate

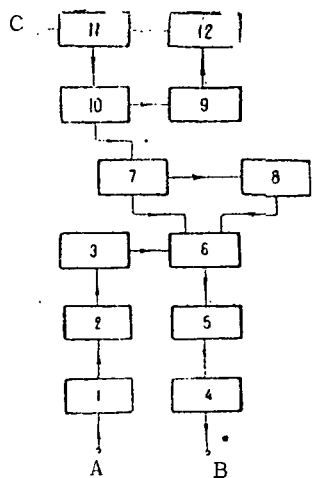


Figure 3. Functional diagram of the unit for shaping the additional main pulse.

load on gating stage 3 from being shunted by the diode. After passage is enabled, the TKT pulse flows to threshold circuit 5, and then to mixing stage 4 in the MO unit (pulse master oscillator). The TKT pulse flows from the MO unit to the transmitter modulator, shaping the AMP.

The trailing edge of the TKT

- passage enabling pulse, 7, generates a TKT inhibit pulse, 8, to prevent passage of subsequent TKT pulses, and thus prevent the shaping of the second, third, and other AMP. The TKT inhibit pulse is 25-30 msec in width, the time necessary to disconnect the passage enabling stage, 6,

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for the duration of three main pulses from a transmitter with a radar sampling rate of $F_r = 100$ pps.

The command signal triggers intensification resolution stage 9 shaping a 38 msec intensification resolution pulse. The pulse is fed from stage 9 into intensification discriminator 12 and gives the command to intensify four pulses reflected from the meteor trail.

The command signal is fed to a relay that disconnects the receiver from the indicator after 0.05 sec for from 10 sec to 1 min. The relay disconnects the indicator to prevent intensification of a $\tau_e > 0.05$ sec radio echo, and superposition of the vector diagrams.

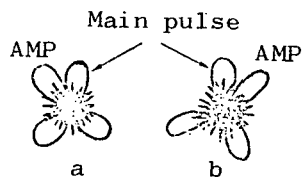


Figure 4. Sample sector recording of meteor echoes.

Figure 4 is a sample sector recording of meteor echoes using an artificial meteor. In conclusion, it should be pointed out that a similar sector recording method is essential for relatively low power radars ($P = 40-60$ kW) with comparatively low pulse frequency

($F_r = 50-200$ pps) and used for measuring meteor trail drifts in space.

REFERENCES

1. Greenhow, J. S., Neufeld, E. L., Phil. Mag., Vol. 1, No. 12, Dec. 1956, pp. 1157-1171.
2. Manning, L. A., Villard, O. G., Peterson, A. M., J. Geophys. Res., Vol. 57, Sept. 1952, pp. 387-403.
3. Sidorov, V. V., Radiometeornyye metody i apparatura dlya nablyudeniya dvizheniy v verkhney atmosfere [Radar Meteor Methods and Equipment for Observation of Movements in the Upper Atmosphere], Thesis, Kazan', 1963.
4. Fialko, Ye. I., Nekotoryye problemy radiolokatsii meteorov [Some Problems of Radar Observations of Meteors], TGU Press, Tomsk, 1961.
5. Robertson, D. S., Liddy, D. T., Elford, W. G., J. Atmos. and Terr. Phys., Vol. 4, No. 4-5, 1953, pp. 255-270.
6. Greenhow, J. S., Philos. Mag., Vol. 45, No. 364, 1954, pp. 471-490.

DETERMINATION OF DIFFUSION IN THE METEOR ZONE

A. Ryskulov

ABSTRACT. The results of the measurement of the coefficient of ambipolar diffusion in the meteor zone are presented.

This paper presents the results of the measurement of the coefficient of ambipolar diffusion in the meteor zone, obtained by an SOM-1 radar in 1964-1965. The measurements were made over a five to eight day period of each month in accordance with the unified, agreed, IQSY program.

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The equipment used for the research is described in reference [1]. The area illuminated by the antenna and in which diffusion was studied, was of the order of 300 x 300 km.

Meteors entering the earth's atmosphere hourly burn up and leave a cylindrical trail. This trail is broken up by diffusion, recombination, and electron adhesion processes, by ionospheric winds, and the like.

The experimental data tell us that the duration of meteor trail reflections varies from 0.02 sec to 1 min. This is explained by the fact that meteors have different masses and velocities which determine the electron line density in the trail.

T. Kaiser and R. Klaus have shown that two types of meteor trails are distinguishable according to electron density.

The first includes meteor trails with electron density $\alpha < \leq 2.4 \cdot 10^{12}$ e/cm, called underdense trails. The diffusion coefficient for these trails can be determined from

$$D = \frac{\lambda^2}{16\pi\tau_{0.5}} \quad (1)$$

where

λ is the wavelength;

$\tau_{0.5}$ is the duration of the reflection from the meteor trails at the 0.5 level.

The second group of meteor trails includes trails with electron density $\alpha \geq 2.4 \cdot 10^{12}$ e/cm, called dense trails. The diffusion coefficient for

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these trails is determined from [2, 3]

$$D = \frac{\lambda}{16\pi^2(s-1)} \cdot \frac{\ln \frac{N_1}{N_2}}{(\tau_2 - \tau_1)} \quad (2)$$

where

N_1 and N_2 are the numbers of reflected signals with duration
 $\tau \geq \tau_1$ and $\tau \geq \tau_2$;

s is the index of the degree of meteor mass distribution, equal to

$$s = 1 + \frac{4}{3} \frac{\ln \frac{N_1}{N_2}}{\ln \frac{\tau_2}{\tau_1}}.$$

Trails of the intermediate type were not used for the calculation [5].

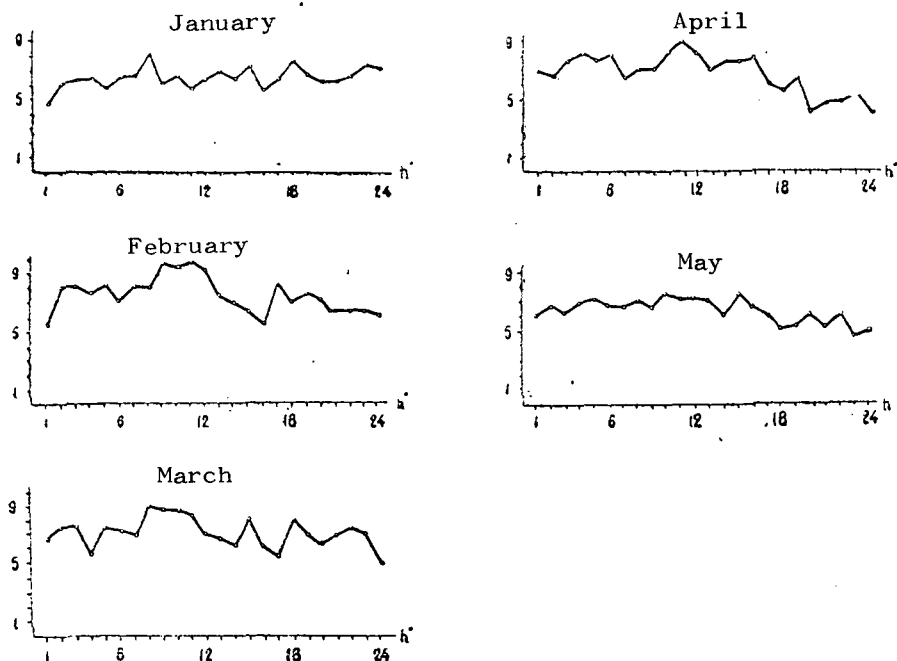


Figure 1. Daily changes in the diffusion coefficient.



Figure 2. Seasonal changes in the diffusion coefficient for 1964-1965.

Figure 1 shows the daily changes in the diffusion coefficient for 1965, calculated using Eq. (1) for underdense trails. Summing the data without altitude separation resulted in a wide scatter in the hourly diffusion values.

The curves in Figure 1 show that the mean daily coefficient of ambipolar diffusion is approximately $D \approx 6-8 \text{ m}^2/\text{sec}$. There were individual months when the daily diffusion rate had an amplitude of the order of $3 \text{ m}^2/\text{sec}$, with the diffusion maximum occurring during the morning

and daylight hours, something that evidently is associated with expansion of the atmosphere and reduction in the density at the corresponding altitudes.

Figure 2 shows the seasonal change in the diffusion coefficient for 1964-1965. The diffusion coefficient minimum occurs in the winter months ($D \approx 4 \text{ m}^2/\text{sec}$) and the maximum in the summer ($D \approx 7 \text{ m}^2/\text{sec}$). This change may also be caused by the heating action of solar radiation.

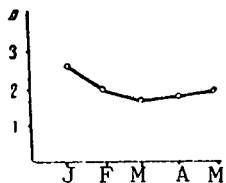


Figure 3. Seasonal change in the diffusion coefficient for overdense trails.

Figure 3 shows the seasonal change in the diffusion coefficient, calculated using Eq. (2) for dense trails. The mean diffusion coefficient is approximately $D \approx 2 \text{ m}^2/\text{sec}$.

This difference in diffusion coefficients for underdense and dense trails for the same hour and month of study shows the inaccuracies in Eq. (2) and the significantly greater

scatter in the altitudes of reflecting points for dense trails and of the application of different effects (polarization, resonance, fading, and wind) on the determination of the duration of trail existence.

In our opinion, diffusion coefficients should be measured using Eq. (1) only for a limited altitude (90-95 km), as B. L. Kashcheyev [4] has already pointed out.

Conclusions

1. The mean diffusion coefficient for the underdense type is approximately $D \approx 6-8 \text{ m}^2/\text{sec}$, with a daily amplitude of the order of $3 \text{ m}^2/\text{sec}$.
2. The values of the diffusion coefficient increase in the summer months by a factor of 1.5 as compared to the winter values.

REFERENCES

1. Karimov, K. A., Kostromin, V., Berezovskiy, M. I., "Radar Installation for Observing Meteors in Kirghizia," Sb.: Meteornoye rasprostraneniye [Collection: Meteor Propagation], Kazan', 1966. /67
2. Fialko, Ye. I., Nekotoryye problemy radiolokatsii meteorov [Some Problems of Radar Observations of Meteors], Tomsk, 1961.
3. Peregudov, F. I., Kharakteristika meteora, kak radiolokatsionnoy tseli [Characteristics of a Meteor as a Radar Target], Tomsk University Press, 1960.
4. Kashcheyev, B. L., "Investigation of the Properties of the Upper Atmosphere by Radar Observations of Meteors," Sb.: Meteory [Collection: Meteors], 2-3, KhPI, 1963.
5. Fialko, Ye. I., "A Method for Measuring Electron Line Density and Diffusion Coefficient Using Meteor Radio Echoes from an Intermediate Body," Geomagnetizm i Aeronomiya, 1965.

DETERMINATION OF THE PARAMETER s

V. D. Kostromin

ABSTRACT. Experimental data for determining the parameter s , characterizing the distribution of meteoric bodies in terms of mass, are presented.

This paper presents experimental data for determining the parameter s characterizing the distribution of meteoric bodies in terms of mass, obtained by an SOM-1 radar during 1964-1965. The equipment, and the procedure involved in the observation of meteoric activity, are described in reference [1, 2].

The parameter s was determined from [3]:

$$s = 1 + \frac{4}{3} \frac{\ln \frac{N_1}{N_2}}{\ln \frac{\tau_2}{\tau_1}}, \quad (1)$$

where

N_1 is the number of meteors with duration $\tau \geq \tau_1$;

N_2 is the number of meteors with duration $\tau \geq \tau_2$.

Reflections with durations longer than 10 seconds were excluded.

Meteor echoes with durations $\tau_1 \leq 0.2$ sec and $\tau_2 = 0.4$ sec were used for the calculation to ascertain the behavior patterns in the change in the parameter s over a 24-hour period, from day to day, and over a period of a year. Then s can be found from

$$s = 1 + 1.972 \ln \frac{N_1}{N_2}, \quad (2)$$

where

N_1 is the number of meteors whose duration exceeds τ_1 ;

N_2 is the number of meteors whose duration exceeds τ_2 .

The meteor data, taken from film, were transferred to punched tape and processed by a "Minsk-1" type all-purpose digital computer.

Figure 1 shows the results of the determination of the parameter s for

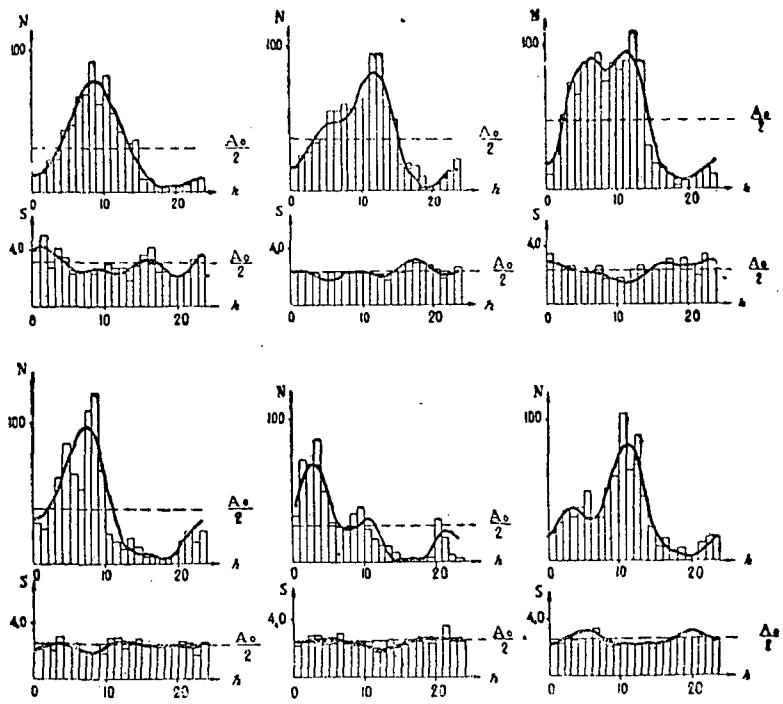


Figure 1. Values of parameter s for 1964-1965.

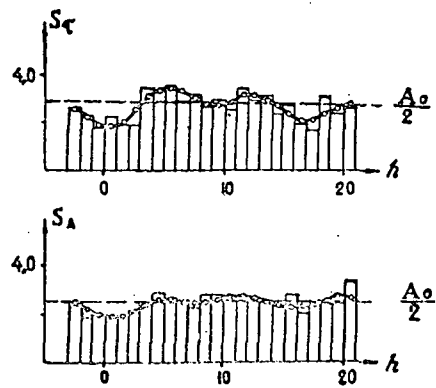


Figure 2. Daily changes in parameter s .

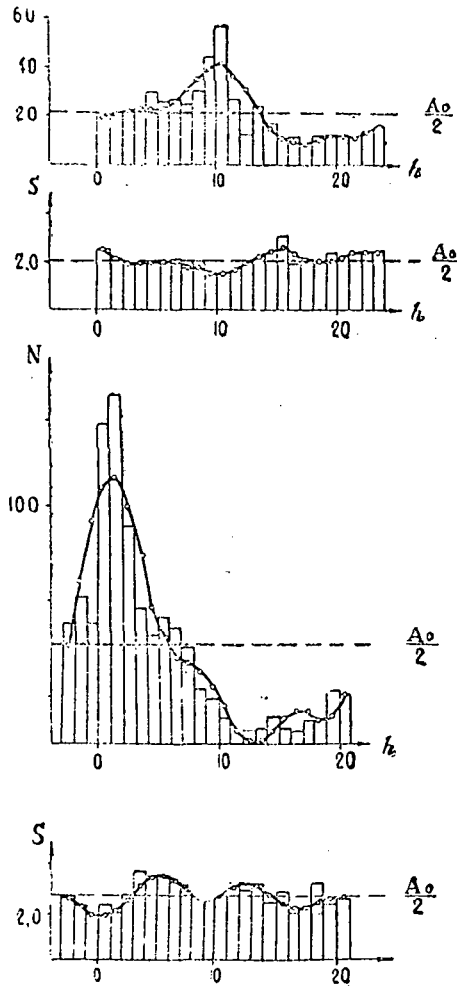


Figure 3. Values of the parameter s calculated for meteor streams.

1964-1965. Determination of the parameter s in terms of amplitude-time characteristics is more precise [4, 5], so s was measured using

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$$s = 1 + k \ln \frac{N_1}{N_2}, \quad (3) \quad 71$$

where

N_1 is the number of meteors whose amplitudes exceed the threshold level A_1 ;

N_2 is the number of meteors whose amplitudes exceed the threshold level A_2 ;

k depends on the levels of the A_1 and A_2 readings.

The "Minsk-1" computer was used to process these data as well.

Figure 2 histograms show the determination of s by two methods, and are presented for purposes of comparison. These histograms show that the parameter s has a daily pattern. The amplitude of the first harmonic is small ($A_1 = 0.5$), but distinguishable. Accuracy in determining s is of the order of 60%. This indicates the inhomogeneity of meteor material distribution along the celestial latitude.

The parameter s has a tendency to decrease during the activity of apex and solar maxima. Possibly this indicates a difference in the structure of the sporadic meteor background.

Figure 3 shows the results of determining s for several streams. There is a reduction in s with increase in number, but with some delay. The dip in s in the time interval $h_1 - h_2$ can indicate a concentration of larger particles. The distribution of meteoric material in streams can be studied using this method. The time delay between the number maximum and the s minimum apparently indicates the Poynting-Robertson effect. More detailed and longer radar observations of meteor streams will aid in the evaluation of the influence of the Poynting-Robertson effect on the evolution of meteor stream orbits.

Conclusions

1. The daily pattern of the parameter s indicates the heterogeneity of meteor material with respect to the celestial latitude.
2. A decrease in s is observed in the region of apex and solar maxima. This may indicate a difference in the structure of the sporadic background in the apex and solar directions.
3. The study of the parameter s can help in explaining the distribution of meteor material and in evaluating the influence of the Poynting-Robertson effect for streams.

REFERENCES

1. Karimov, K. A., Kostromin, V. D., Berezovskiy, M. I., "A Radar Installation for Observing Meteors in Kirghizia," Sb.: Meteornoye rasprostraneniye [Collection: Meteor Propagation], Kazan', 1966. /72
2. Karimov, K. A., Kostromin, V. D., "Radar Observations of Meteor Activity in Frunze Under the IQSY Program, 1965, Using Two Radars," Sb.: Meteornoye rasprostraneniye [Collection: Meteor Propagation], Kazan', 1966.
3. Fialko, Ye. N., Nekotoryye problemy radiolokatsii meteorov [Some Problems of Radar Observations of Meteors], Tomsk University Press, 1961.
4. Pupyshev, Yu. A., Meteornoye rasprostraneniye radiovoln [Meteor Propagation of Radio Waves], Part 2, Kazan', 1964.
5. Bel'kovich, O. N., Meteornoye rasprostraneniye radiovoln [Meteor Propagation of Radio Waves], Part 2, Kazan', 1964.

RESONANCE EFFECTS DURING SCATTERING AND ABSORPTION OF RADIO WAVES IN MODELS OF TRAILS OF FAST MOVING BODIES IN THE IONOSPHERE

L. A. Zhizhimov

ABSTRACT. A mathematical analysis is made of resonance effects in meteor trails during radio wave scattering and absorption.

It is known [1] that the region of a trail left by a moving body in the ionosphere can have natural oscillations and that the existence of a wave number whose squared reciprocal is close to zero is analogous to the emergence of a "bound state" with a near-zero energy level in quantum mechanics. Therefore, resonance scattering of TM waves transmitted from the earth can take place in a trail with the shape of an infinite circular cylinder, the electron concentration in which depends only on the radius. /73

The trail may not have the true symmetry of a circular cylinder under real conditions, and generally speaking is flattened by the earth's magnetic field degenerating into a strip, and then into a flat layer. We can, in order to take into consideration this effect on the scattering cross section radio wave frequency ratio, consider the problem of resonance scattering on an elliptical cylinder of infinite length in which the semiminor axis, b , is less than a wavelength, while the ratio between the wavelength and the semimajor axis, a , is arbitrary.

The scattering cross section in this cylinder, as we know [3], has the following form in the case of normal incidence (parallel to the semiminor axis) of a plane TM wave

$$\sigma = \frac{8\pi}{k} \sum_{m=0}^{\infty} \frac{Se_m^2(h, 0)}{N_m(h)} \sin^2 \delta_m, \quad (1)$$

where

$Se_m(h, \cos \varphi)$ is the Mathieu function,

$$N_m(h) = \int_0^{2\pi} Se_m^2(h, \cos \varphi) d\varphi,$$

$h = \kappa a$, δ_m are phase shifts. /74

Assuming that for given length a there exists a single eigenvalue, $\kappa_0 = -i\kappa$, close to zero, which is a nonessential singularity in the scattering

amplitude, it is not difficult to find the value of the phase, δ_m , close to resonance from the results [1]

$$\delta_m \approx -\operatorname{arctg} \frac{x}{x_0}. \quad (2)$$

Let us limit ourselves to establishing the obvious dependence of the scattering cross section on h for a band greatly elongated along the OX axis (along a), when the contribution of the ends distant from the center to scattering can be ignored. The basic contribution to the value of the Mathieu functions $Se_m(h, \cos\varphi)$ is made by angles close to $\varphi = \pm \pi/2$ [3] for large values of the parameter $h = \kappa a$. On the other hand, the $Se_m(h, z)$ functions are proportional to radial Mathieu functions of the first kind, $Ie_m(h, z)$ [3], which, for arbitrary h , can be represented in the form of an expansion in Bessel functions

$$Ie_m(h, z) = \sum_{n=0}^{\infty} B_n(h, m) I_n(hz). \quad (3)$$

The influence of the ends of the band obviously will be nonexistent if, for given h and $z \rightarrow 0$, one is limited to just the first term in Eq. (3).

Then, substituting Eqs. (2) and (3) into Eq. (1) the approximation result is

$$\sigma = \frac{2\pi^2 \kappa h}{x^2 + x_0^2} \left(\int_0^{x_0} \frac{\sin^2 x}{x^2} dx \right)^{-1}, \quad (4)$$

where

$$x_0 = \frac{\pi^2 h}{2}.$$

Eq. (4) should be proportional to the transmission coefficient, T , for a plane layer when $h \rightarrow \infty$. Actually, Eq. (4) yields for $h \rightarrow \infty$

$$\sigma = \frac{2\pi^2 \kappa h 8}{x^2 + x_0^2} \left(\int_0^{x_0} \frac{\sin^2 x}{x^2} dx \right)^{-1} = \frac{4\pi a x^2}{x^2 + x_0^2}. \quad (5) \quad \angle 75$$

Hence

$$\left. \begin{aligned} T &= \frac{\sigma}{4\pi a} = \frac{x^2}{x^2 + x_0^2} \\ R &= 1 - T = \frac{x_0^2}{x^2 + x_0^2} \end{aligned} \right\}, \quad (6)$$

which coincides with the resonance coefficients of transmission and reflection from a plane layer [1].

Eq. (4) should be valid as well for $h \rightarrow 0$ (the contribution of ends, and maximum deviations of the cross section from a circle are obviously not significant in this case), when the integral in the denominator of Eq. (4) equals $\pi^2 h/2$

$$\sigma = \frac{4x}{x^2 + x_0^2} \quad (7)$$

The last result can be generalized for the case of an extended region of finite length, L , if the connection between the amplitudes of the scattering in a three-dimensional region and a two-dimensional one is used [2]

$$\sigma = \frac{4xL}{x^2 + x_0^2(L)} \quad (8)$$

where the eigenvalue $x_0(L)$, close to zero, exists only for

$$L_{cr} \geq \frac{1}{x_0(\infty)}.$$

It is interesting to note that Eq. (8) is the limit case for resonance scattering of scalar waves by a prolate spheroid, if one excludes the influence of its ends on the scattering

$$\sigma = \frac{4\pi h}{x^2 + x_0^2} \left(\int_0^h \frac{\sin^2 x}{x^3} dx \right)^{-1}, \quad (9)$$

where

$h = \kappa c$, and $2c$ is the interfocal distance for the spheroid.

Taking the limit as $h \rightarrow \infty$ in expression (9), we get (8), and as $h \rightarrow 0$ we get Wigner's result in quantum mechanics

$$\sigma = \frac{4\pi}{x^2 + x_0^2} \quad (10)$$

The results obtained are true for a nonabsorbing plasma when the degree of perturbation, U , is real, something that is valid for example, for perturbations caused by a moving body in the upper layers of the ionosphere,

by interplanetary gas, or by outer space, without including the effect of a permanent magnetic field. Under these conditions the length of the free particle path, l , is long compared to the dimensions of the moving body, so the influence of collisions on the perturbation of particle concentration is insignificant in a large region in the vicinity of the body. Collisions between particles begin to have an effect only at long distances from the body (of the order of the free path length), as well as in the lower layers of the ionosphere, where the free path length is not as long. The influence of collisions between particles therefore must be taken into consideration in these regions; that is, the perturbation of a complex magnitude must be taken into consideration. The complex magnitude of the perturbation implies that at distances of the order of the path length the trail region, based on its scattering properties, is analogous to a complex potential well, in which absorption is significant as well as scattering. Absorption can be the principal effect if the energy of the scattered particle vanishes.

Let us, in order to explain the qualitative features of complex perturbation on the process of scattering and absorbing radio waves in a trail, consider the problem of the scattering of a TM wave by a low-capture cylindrical inhomogeneity. The small imaginary part of the perturbation makes the phase angles, δ_m , contained in the scattering amplitude, complex

$$\tilde{\delta}_m = \delta_m + i\alpha_m, \quad (11)$$

where

$$\operatorname{Re} \tilde{\delta}_m \gg \operatorname{Im} \tilde{\delta}_m,$$

α_m is proportional to the frequency of collisions between particles.

Based on the arguments, the work in reference [1] can only be limited by a wave with $m = 0$. The scattering and absorption cross sections then can be calculated using the formulas [3]

$$\sigma_s = \frac{1}{x} \left| 1 - e^{2i\tilde{\delta}_0} \right|^2,$$

$$\sigma_n = \frac{1}{x} \left(1 - \left| e^{2i\tilde{\delta}_0} \right|^2 \right) \approx \frac{4 |\alpha_0|}{x}.$$

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The phase angle in the resonance region is approximately

$$\delta p_0 \approx -\operatorname{arctg} \frac{x}{x_0},$$

therefore

$$\sigma^p_s \approx \frac{4x}{x^2 + x_0^2} (1 - 2|\alpha^p_0|),$$

$$\sigma^p_n = \frac{4|\alpha^p_0|}{x}. \quad (12)$$

Far from the resonance $\sigma_0 = \lambda_0$, $\alpha_0 = \alpha_0^0$, therefore

$$\sigma^0_s = \frac{4}{x} (1 - 2|\alpha^0_0|) \sin^2 \lambda_0,$$

$$\sigma^0_n = \frac{4|\alpha^0_0|}{x}, \quad (13)$$

and $\lambda_0 \sim (\kappa a)^2$, such that $\sigma^0_s \sim \kappa^3 a^4$, where a is the effective radius of the cylindrical inhomogeneity.

Comparing Eqs. (13) and (12), we see that when $\kappa \rightarrow 0$ the absorption becomes the dominant effect if κ is not in the resonance region. The ratio of the scattering cross section far from the resonance to the cross section is of the order of $\kappa^4 a^4 / \alpha^0_0$, such that $\sigma^0_s < \sigma^0_n$ if $\alpha^0_0 > \kappa^4 a^4$.

Conversely, near the resonance, when $\kappa = \kappa_0$

$$\sigma^p_{smax} = \frac{2}{x_0} (1 - 2|\alpha^p_{0max}|), \quad (14)$$

$$\frac{\sigma^p_{smax}}{\sigma^p_{nmax}} \approx \frac{1}{2|\alpha^p_{0max}|},$$

and since $\alpha^p_{0max} \ll 1$, then $\sigma^p_s \gg \sigma^p_n$; that is, in this case resonance scattering can be the dominant effect.

The value of the imaginary part of the phase angle contained in the absorption and scattering cross sections can be determined by the method of analytical continuation from the region of actual phase values to a complex region.

For simplicity let us limit ourselves to a model independent of perturbation coordinates with a sharp boundary such that in the trail region

$$\tilde{U}_0 = U_0 + i\gamma$$

that is, the permittivity in the region of perturbing activity is complex

$$\tilde{\varepsilon} = \varepsilon_1 + i\varepsilon_2 = \tilde{n}^2 = (n_1 + in_2)^2 \approx n_1^2 + 2in_1n_2,$$

hence

$$\varepsilon_1 = n_1^2, \quad n_2 = \frac{\varepsilon_2}{2\sqrt{\varepsilon_1}}.$$

Expanding $\tilde{\delta}_0$ in a Taylor series, we obtain

$$\alpha_0 = n_2 \frac{\partial \tilde{\delta}_0}{\partial n_1} = \frac{\partial \tilde{\delta}_0}{\partial \varepsilon_1} I_m \tilde{\varepsilon}.$$

The phase δ_0^0 (the "potential scattering" phase) is equal to [2]

$$\delta_0^0 = \frac{\pi a^2 \kappa^2}{4} \left| \frac{\varepsilon_1}{\varepsilon_0} - 1 \right|,$$

where

ε_0 is the permittivity outside the trail. Then

$$\sigma_n^0 = \frac{\pi a^2 \kappa^2}{x} I_m \tilde{\varepsilon},$$

$$\sigma_s^0 = \frac{\pi^2 a^4 \kappa^3}{4} \left| \frac{\varepsilon_1}{\varepsilon_0} - 1 \right|^2.$$

Hence, it will be seen

$$\sigma_n^0 > \sigma_s^0, \quad (15) \quad /79$$

if

$$I_m \tilde{\varepsilon} > \frac{\pi a^2 \kappa^2}{4} \varepsilon_1.$$

Inequality (15) is a consequence of the fact that when $\lambda_0 \rightarrow \infty$ (λ_0 is the wavelength in free space) $\sigma_n^0 \sim a^2/\lambda_0$ at the same time that $\sigma_s^0 \sim a^4/\lambda_0^3$ [2]. Near resonance, $\delta_0^p \approx -\arctan(\kappa/\kappa_0)$, where

$$x_0 = \frac{2}{a} \exp(-^2/\kappa^2 a^2 \varepsilon_1),$$

therefore

$$\alpha^2 = \frac{x x_0 \ln \frac{2}{x_0 a}}{x^2 + x_0^2} \cdot \frac{I_m \tilde{\varepsilon}}{Re \tilde{\varepsilon}},$$

$$\sigma_n^p = \frac{4x_0}{x^2 + x_0^2} \ln \frac{2}{x_0 a} \cdot \frac{Im \tilde{\varepsilon}}{Re \tilde{\varepsilon}},$$

$$\sigma_s^p \approx \frac{4x}{x^2 + x_0^2}.$$

Hence, we obtain the fact that the ratio of the maximum resonance absorption and scattering cross section is equal to $(\text{Im}\tilde{\epsilon}/\text{Re}\tilde{\epsilon}) \ln^2/\kappa_0 a$. And since $\text{Im}\tilde{\epsilon} \ll \text{Re}\tilde{\epsilon}$, then a given, $\kappa_0 \sigma_{n \max}^p \ll \sigma_{s \max}^p$ if $(\text{Im}\tilde{\epsilon}/\text{Re}\tilde{\epsilon}) \ll 1/\ln(2/\kappa_0 a)$.

Similar calculations can be made for perturbation U , which is coordinate-dependent.

Thus, resonance scattering of radio waves in models of trails of rapidly moving bodies in the ionosphere depends significantly on trail symmetry, its electron concentration, and the polarization of the scattered radio waves. A quantitative evaluation of the resonance scattering cross section reveals that when conditions are favorable, the scattering cross section can exceed the effective trail surface by a factor of several score.

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REFERENCES

1. Sayasov, Yu., Zhizhimov, L. A., Radiotekhnika i elektronika, No. 499, 1963.
2. Van-de-Huest, H. C., Rasseyaniye sveta malymi chastitsami [Scattering of Light by Small Particles], IL, 1961.
3. Morse, M., Feshbach, G., Metody teoreticheskoy fiziki [Methods of Theoretical Physics], Vol. II, IL, 1960.

THE EFFECT OF MOUNTAIN BARRIERS IN THE PATH OF METEOR
PROPAGATION OF RADIO WAVES

N. N. Kalinina

ABSTRACT. The effect of mountains in the propagation path on the propagation of radio waves by meteors is discussed. The results are compared with propagation paths across plains.

The question of the effect mountains in the path of radio wave propagation have on meteor propagation has not yet been considered. /81

As is known, the propagation of radio waves over radio paths through meteor trails is possible if the radio waves are properly oriented and are in a region in which meteor radio propagation is possible. This region, which from now on will be called the permissible region, after K. V. Kostylev, is a part of the meteor zone of the ionosphere, and is simultaneously visible from both ends of the path.

Mountains in the path of radio wave propagation reduce the permissible region, causing primarily a change in the values of such fundamental characteristics of meteor radio propagation as the number of meteor reflections and the duty cycle in the coupling line. However, this article will not consider these effects, nor will it consider the features associated with diffraction and interference from possible reflections of radio waves from mountains.

We will examine only the magnitude of the change in the permissible region of four arbitrarily chosen paths over mountainous terrain (Table 1, columns 2-5), characteristic of which is the fact that the end points of the path, T and R, rise to some heights h_T and h_R above the surface of the terrestrial spheroid, and that there are mountains near these points along the radio wave propagation path.

Let us call the paths, the end points of which are on the surface of the terrestrial spheroid, the "plain" paths, and those with mountains in the radio wave propagation path "mountain" paths.

If T^* and R^* designate the transmission and reception points of a plain path, and T and R the points of a mountain path at heights h_T and h_R above the terrestrial spheroid, then the apparent horizon lines H_T /82

and H_R , for points T and R descend below the horizon lines H_{T^*} and H_{R^*} for the points T^* and R^* .

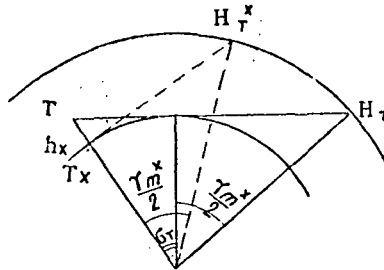


Figure 1. Geometry of the position of points on the apparent and true horizons points H_T and H_{T^*} for points T and T^* for mountain and plain paths, respectively.

From Figure 1 we obtain

$$\frac{\gamma_m^*}{2} < \frac{\gamma_m^*}{2} + \sigma_n = \gamma_{mn}, \quad (1)$$

where

$$\cos \sigma_n = \frac{R}{R + h_n}, \quad (2)$$

$n = T, R.$

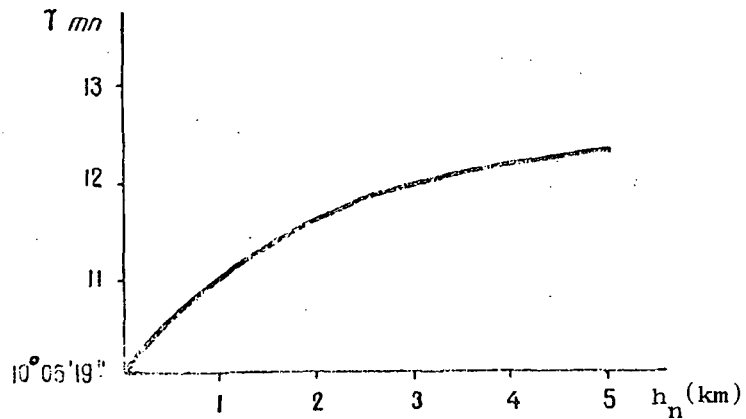


Figure 2. The angle γ_{mn} in terms of the height of the end point of a mountain meteor path.

TABLE I

Path No.	Length of path, γ , in degrees	Length of path, $2L$, in km	point	h_n	S , mountain path relative units	S^* , plain path relative units	$\frac{S - S^*}{S^*}$, %	Limit of path, γ_m , in degrees	Extended limit of path, %	Extended limit of path, km	S_{shadow} , relative units	$\frac{S_{\text{shadow}}}{S}$, %
1	1°54'4"	213	T	0.68	3.46	2.81	23	22°18'08"	10.5	235.4	1.92	56
			R	1.62								
2	6°18'0"	700	T	0.68	2.36	1.92	23	21°52'18"	8.4	188.3	1.38	58
			R	A.72								
3	8°03'2"	895	T	0.72	1.93	1.60	21	21°32'18"	6.7	150.2	0.79	41
			R	0.24								
4	12°58'4"	1440	T	0.68	1.00	0.76	32	21°30'38"	6.6	148.0	0.36	36
			R	0.24								

Figure 2 shows angle γ_{mn} in terms of height, h_n . The value of angle γ_{mn} is taken from $\gamma_m^*/2 = 10^\circ 05' 19''$ (for earth radius $R = 6367.6$ km) for $h_n = 0$ to γ_{mn} corresponding to $h_n = 5$ km.

Thus, what follows from Figures 1 and 2 and Eqs. (1) and (2) is that there will be a marked increase in the permissible region because of the rise in heights of the end points of the mountain path, or of one of the points. The degree of this increase can be found by constructing stereographic projections of the permissible regions of the T^*R^* and TR paths, using the method described in reference [1], and then comparing their areas.

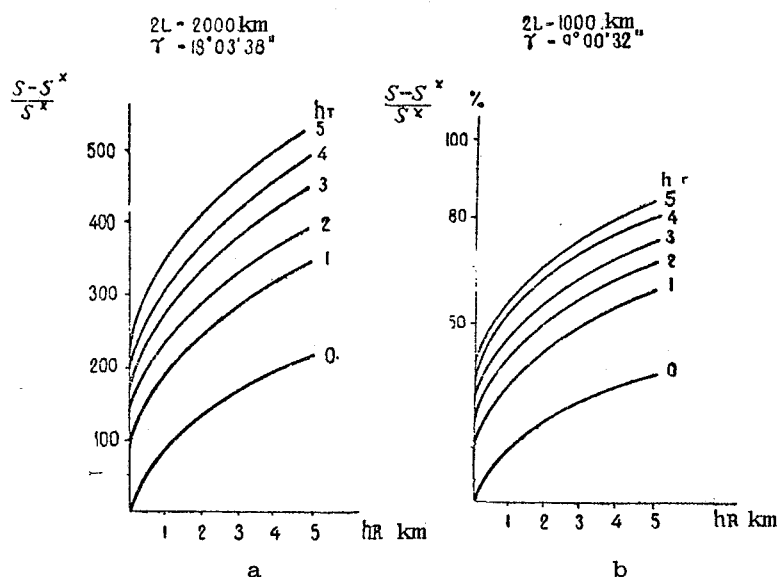


Figure 3. a, b: Relative increase in the area of the permissible region in terms of elevation of path end point.

Areas S^* and S of the permissible regions of paths T^*R^* and TR were measured in relative units (Table 1, columns 6, 7, and 8). There is no definite behavior pattern for change in relative increase in the permissible region, $(S - S^*)/S^*$, with h_T , h_R , and γ , because the calculation was made for paths of different lengths. This pattern was ascertained by establishing the relationship between $(S - S^*)/S^*$ and h_n when $\gamma = \text{constant}$, for $\gamma = 9^\circ 00' 32''$ (1000 km), $18^\circ 03' 38''$ (2000 km), and $h_n = 0-5$ km. Figure 3, a and b, shows the results.

These figures make it evident that the relative increase in the area of the permissible region increases with elongation of the path and with

rise in one, or both path and points, when paths are of different lengths. The rate of increase is higher for paths near the limiting plain path and, for a constant path length, for rise in points T and R from 0 to 1 km. Rise in both path points to a height of 5 km results in the permissible region for a 1000 km path length increasing to the permissible region of a 508.6 km plain path, and for a 2000 km path to the permissible region of a 1505.4 km path.

In the case of a plain path, angle γ_m^* determines the length (in measurement degrees) of that limiting path (≈ 2240 km), for which the permissible region becomes a point.

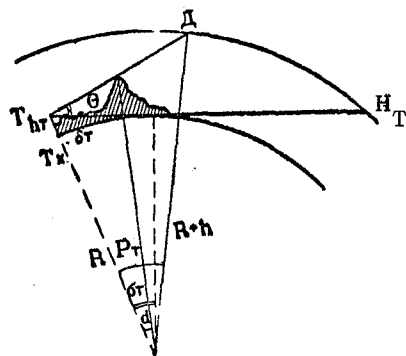


Figure 4. For the derivation of Eq. (4).

In the case of mountain paths, for which $h_T \neq 0$ and $h_R \neq 0$, the length of the limiting path (also in degrees), will be determined by the angle

$$\gamma_m = \gamma_m^* + \sigma_T + \sigma_R, \quad (3)$$

where

σ_T and σ_R are found using Eq. (2).

Consequently, when points T and R rise to some heights $h_T + h_R$, the limiting mountain path elongates to a magnitude (in degrees) of the angle $\sigma_T + \sigma_R$, and is a variable that depends on σ_T and σ_R , and therefore, on h_T and h_R (see Table 1, columns 9, 10, and 11).

To make apparent the degree of decrease in the area of the permissible region caused by the presence of mountain chains in the path of meteor

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radio propagation we plotted terrain chartlets from topographic maps for each end point of the four paths cited on azimuths of ψ_n ($n = T, R$) in

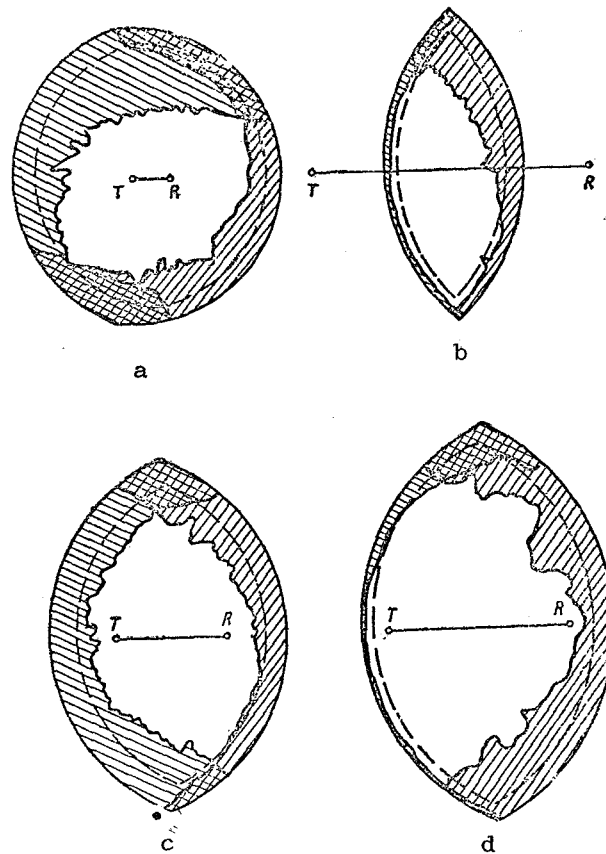


Figure 5. Mountain shadow relief in the permissible region:
a - path No. 1; b - path No. 4; c - path No. 2; d - path No. 3.

2° increments. These provided mountain heights, H , with the largest angles of elevation, Θ , and their distances, L , to a designated point on the path. Knowing H and L , we found angle Θ by using the equation

$$\text{ctg}(\sigma n - \Theta) = \frac{(R+H)\sin\alpha}{(R+h_n) - (R+H)\cos\alpha}, \quad (4)$$

where

$$\alpha = \frac{180 \cdot L}{\pi R}, \quad (5)$$

R is the radius of the earth (Figure 5). Then, using

$$\sin \rho_n = \frac{r_n \cdot \cos(\sigma_n - \Theta)}{R + h} \quad (6)$$

where

$$r_n = (R + h_n) \sin(\sigma_n - \Theta) + \sqrt{(R + h)^2 - (R + h_n)^2 \cos^2(\sigma_n - \Theta)} \quad (7)$$

and

h is the mean height of the reflection points in the meteor zone, angles ρ_n ($n = T, R$) were obtained for each azimuth ψ_n .

Then the mountain shadow relief was constructed for each path, using the coordinates $\psi_n \rho_n$ for a calculated shadow point and a stereographic grid [11]. The area between the relief and the limits of the permissible region is hatched. The crosshatching shows the shadow areas. That part of the relief designated by the dashed line was obtained from insufficient data because necessary topographic maps were unavailable (Figure 5 a, b, c, d).

The results of measurements of the shadow areas, S_{shad} , in relative units, and the S_{shad}/S calculation in %, are listed in the table.

As will be seen from the table (columns 12 and 13), the areas of the permissible regions shadowed by mountains are quite extensive for all four paths.

Mountains obviously will offer particularly great interference on paths close to the limit in length.

Conclusions

1. There is a definite increase in the region permissible for meteor radio wave propagation over mountain paths, the end points of which are at some height above the surface of the earth.

2. The presence of mountain barriers along the path of meteor radio propagation leads to attenuation of part of the permissible region fringe, reducing the area of the permissible region. The reduction is greater the higher the mountains, or the closer they are to the end points of the path.

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Mountains have an especially large interference affect on paths with lengths close to the limit, and this must be taken into consideration when planning the corresponding lines for meteor radio communication in mountainous terrain.

REFERENCE

1. Kalinina, N. N., "A Graphical Method for Determining the Geometric Parameters of Meteor Propagation of Radio Waves," Sb.: Meteornoye rasprostraneniye radiovoln [Collection: Meteor Propagation of Radio Waves], No. 3-4, KGU Press, Kazan', 1966.

A GRAPHICAL METHOD FOR ESTABLISHING THE ACTIVE CURVE OF A METEOR
RADIANT POINT ON A GIVEN PATH

N. N. Kalinina

ABSTRACT. A graphical method for determining the positions of reflecting points of the active curve of a radiant point is described.

A meteor radiant point above the plane of the horizon of a given path point, N^1 , appears on the path such that at each moment in the time considered meteor trails associated with it can reflect a radio signal at points forming a curve on a sphere that K. V. Kostylev has proposed we call the active radiant curve [1, 2] (the radius is $R + h$, where R is the radius of the earth, and h is the mean altitude of the meteor zone).

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In order to solve certain of the basic problems of meteor burst propagation, and particularly those concerned with forecasting the number of meteor reflections and the communication line duty cycle, we must begin with a determination of geometric parameters of that propagation directly associated with the reflecting points of the active radiant curve.

A strictly analytical calculation of the coordinates of reflecting points for the particular radiant point reduces to an eighth-degree trigonometric equation, precise solution of which is possible only by using a computer, something that is not always possible. An approximate solution, using conventional computational means, takes a great deal of time and effort.

The proposed graphical method of determining the positions of the reflecting points of the active radiant curve on the $R + h$ sphere, and, as a result, their coordinates, is relatively simple, takes little time for construction, and is reasonably accurate. It is based on satisfying the following three basic conditions for meteor burst propagation:

1. the reflecting point in the meteor trail should be visible from both end points of the path, T and R ;

1. Path point N is the foot of a perpendicular dropped from the center of the earth to the path line.

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designated in Figure 1 as p_0 . Now let us take $\zeta_0 \eta_0$ for the spherical coordinates of point p_0 .

Pole q_0 in Figure 1 does not coincide with reflecting point p_0 . Angle Z_0 is larger than angle ζ_0 , except when $Z_0 = \zeta_0 = 0$. This can be explained by the fact that ζ_0 is the angle between the bearing to the zenith point N of the path and the radius of the $R + h$ sphere (or to the normal to the sphere) at point p_0 , and Z_0 is the angle between this same bearing to the zenith and the normal to the Q_0 -plane at point O , or, what is the same thing, the normal to the Q_0 -plane passing through the point p_0 and which, in turn, is the normal to the specular ellipsoid, the curvature of which is greater than the curvature of the $R + h$ sphere. Point p_0 can lie only in a region suitable for meteor burst propagation bounded by the planes of the horizons of points T and R, and ζ_0 can change from 0 to $10^\circ 05' 09''$ (when the radius of the earth is $R = 6371.21$ km [3]), whereas Z_0 can take values from 0 to 90° .

Nor can the azimuths η_0 and A_0 , read from the path line on the R point side, coincide at points p_0 and q_0 . But there is a definite analytical connection, obtained in the following form, between coordinates $\zeta_0 \eta_0$ and $Z_0 A_0$ of these points

$$\cos Z_0 = \frac{\bar{a}^2 \left(\sec \frac{\gamma_m}{2} \cos \zeta_0 - \right.}{\sqrt{\left\{ \bar{b}^2 \left[\sec \frac{\gamma_m}{2} \sin \zeta_0 \cos \eta_0 + \frac{1}{2} (\sec \sigma_T \sin \gamma_T - \sec \sigma_R \sin \gamma_R) \right] \right\}^2 + \left. \frac{-\sec \sigma_T \cos \gamma_T}{+ \bar{a}^4 \sec^2 \frac{\gamma_m}{2} \sin^2 \zeta_0 \sin^2 \eta_0 + \left[\bar{a}^2 \left(\sec \frac{\gamma_m}{2} \cos \zeta_0 - \sec \sigma_T \cos \gamma_T \right) \right]^2} \right.}} \quad (1)$$

$$\cos A_0 = \frac{\bar{b}^2 \left[\sec \frac{\gamma_m}{2} \sin \zeta_0 \cos \eta_0 + \frac{1}{2} (\sec \sigma_T \sin \gamma_T - \sec \sigma_R \sin \gamma_R) \right]}{\sqrt{\left\{ \bar{b}^2 \left[\sec \frac{\gamma_m}{2} \sin \zeta_0 \cos \eta_0 + \frac{1}{2} (\sec \sigma_T \sin \gamma_T - \sec \sigma_R \sin \gamma_R) \right] \right\}^2 + \left. \frac{-\sec \sigma_R \sin \gamma_R}{+ \bar{a}^4 \sec^2 \frac{\gamma_m}{2} \sin^2 \zeta_0 \sin^2 \eta_0} \right.}} \quad (2)$$

where

a and b are the semimajor and semiminor axes of the specular ellipsoid of rotation divided by the radius of the earth;

$\gamma_m/2 = 10^\circ 05' 09''$ when the radius of the earth is $R = 6371.21$ km;

γ_T and γ_R are segments of the path from points T and R to point N , in measurement degrees;

σ_T and σ_R are the visual angles from the center of the earth to points T and R on the path and, correspondingly, the points of tangency of the horizon lines for these points, T and R , with the terrestrial surface.

There is, thanks to this relation, a unique correspondence between $\zeta_O \eta_O$ and $Z_O A_O$. Using it, it is possible to match a $Z_O A_O$ point with each $\zeta_O \eta_O$ point, and we can construct a stereographic grid with $Z_O = \text{constant}$, $A_O = \text{constant}$ based on the $\zeta_O \eta_O$ stereographic grid and using the method described in [3]. This we shall call the $Z_O A_O$ coordinate grid.

The $Z_O A_O$ coordinate grid calculated for one path is not suitable for another because its appearance will depend on the path length [see Eqs. (1) and (2)]. The $Z_O A_O$ coordinate grid within the limits of a permissible region will have the appearance of that in Figure 2 for a plain path 700 km in length.

Let us now assign the coordinates $Z_1 = Z$ and $A_1 = A_O^* - A$ to the radiant point. Here A_O^* is the azimuth of the bearing to the R point on the path, and Z and A are the horizontal celestial coordinates of the radiant point.

Plane Q_O in Figure 3 is perpendicular to the plane of the drawing and therefore is shown as the straight line $R_a O$. We see that radiant point R_a and pole q_O are disposed at azimuths A_1 and that

$$A_O = A_1 + 180^\circ, \quad (3)$$

while the sum of their zenith distances is

$$Z_1 + Z_O = 90^\circ. \quad (4)$$

The $Z_O A_O$ coordinate grid is a grid of the coordinates of poles

q_0 of planes Q_0 of all possible radiant points, so this grid can be used to plot on tracing paper the pole q_0 in Z_0 and A_0 coordinates, found using Eqs. (3) and (4). Thus, the $Z_0 A_0$ coordinate grid, because of the unique correspondence of points p_0 and q_0 , is used to find the one reflecting point corresponding to the given radiant point.

We must, in order to use the $Z_0 A_0$ grid when determining the other reflecting points of the active curve for the specified radiant point, find the coordinates of the poles of the other Q -planes of the sheaf belonging to the specified radiant point.

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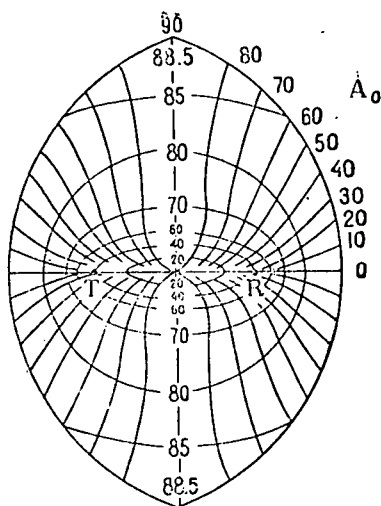


Figure 2. $Z_0 A_0$ coordinate grid for a 700 km long plain path.

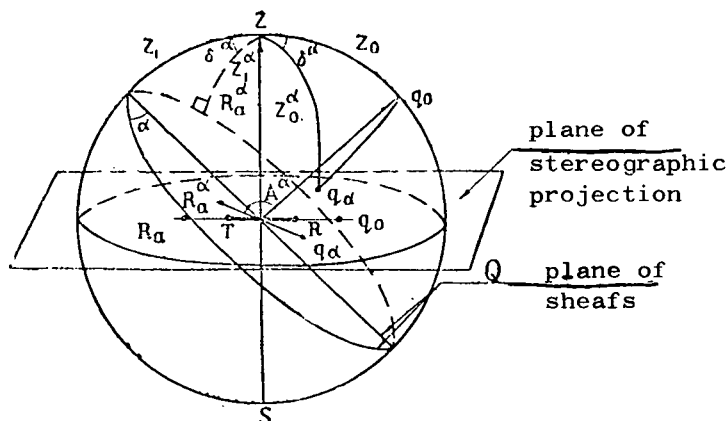


Figure 3. Geometry of the position of pole q_α of plane Q_α of a sheaf positioned at angle α to the initial Q -plane (on the sphere and plane of a stereographic projection).

Let the Q_α -plane of the sheaf be found at angle α to the Q_0 -plane. It is obvious that the position of point R_a^α always can be found such that an arc struck through R_a^α and the zenith point N of the path, once again will pass through pole q_α , which will be at a 90° angle to R_a^α , such that

$$Z_1 + Z_0^\alpha = 90^\circ; \quad (5)$$

$$LR_a Z R_a^\alpha = Lq_0 Z q_\alpha = \delta_\alpha; \quad (6)$$

$$A_0^\alpha = 180 + (A_1 \pm \delta^\alpha), \quad (7)$$

if $h_T = h_R$, or $h_T \neq h_R$ when $Z_1 < 90 - Z_0^O$ and

$$A_0^\alpha = A_1 \pm \delta^\alpha, \quad (7a)$$

if $h_T \neq h_R$ when $Z_1 \geq 90 - Z_0^O$, where $Z_0^O = \left| \frac{\gamma_R - \gamma_T}{2} \right|$.

Angles t_0^α and δ^α can be found from

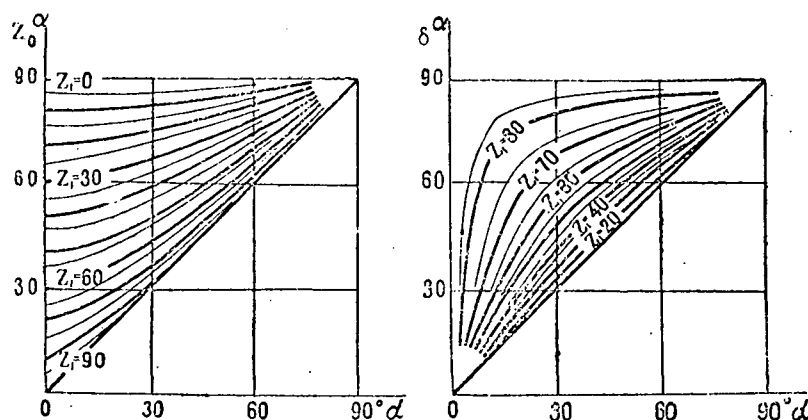
$$\cos Z_0^\alpha = \sin Z_1 \cdot \cos \alpha; \quad (8)$$

$$\cos \delta_\alpha = \operatorname{ctg} Z_1 \cdot \operatorname{ctg} Z_0^\alpha, \quad (9)$$

obtained from the spherical triangle $R_a Z R_a^\alpha$ (see Figure 3). Thus, we obtain the values of the coordinates of the poles of the Q_α -plane corresponding to the specified radiant point for a series of α values.

Z_0^α and δ^α were calculated for different Z_1 using Eqs. (8) and (9) as a matter of convenience and then were used to plot curves (Figures 4 and 5). The curves plotted for $Z_1 = 0 - 90^\circ$ in 5° increments are universal curves suitable for any path. One of the Z_0^α coordinates of pole q^α , corresponding to the specified radiant point, and the angle δ^α between the arcs on which poles q_0 and q_α are located, can be found directly from the curves for specified Z_1 .

Angle δ^α was used to plot the poles, or a second coordinate of the pole, A_0^α , was found using it and Eq. (7).



Figures 4 and 5. Zenith distance of the radiant point, Z_1 , zenith distance of the pole of the Q_α -plane, Z_0^α , and angle δ^α in terms of the angle of inclination of plane Q_α of sheaf α .

Then, as has already been mentioned, poles q_α were plotted on tracing paper according to the values of Z_0^α , δ^α , or Z^α , and A_0^α , using the Z_0A_0 coordinate grid. Connecting them we obtain a curve which, because of the unique correspondence between poles and reflecting points, and the construction of the Z_0A_0 coordinate grid corresponding to it, will be the active curve for the specified radiant point. If necessary, the coordinates $\zeta_0\eta_0$ of the reflecting points of this curve can be determined graphically from the $\zeta_0\mu_0$ coordinate grid, from which the Z_0A_0 coordinate grid had been constructed earlier. The two grids are constructed separately in order not to clutter up the drawing.

The method was checked by constructing five active curves with $h=100$ km /96 for radiant points with coordinates Z_1 and A_1 , equal to 20° and 0° , 20° and 90° , 85° and 10° , 85° and 30° , 50° and 60° (Figure 6, the reflecting points of the active curves are marked x) for a plain path 700 km long, the Z_0A_0 coordinate grid for which is shown in Figure 2. It is 40 cm in diameter (accuracy is adequate).

The five active curves were compared with the active curves for these same radiant points and for the same path, calculated using different formulas and a computer (Figure 6, the reflecting points of the curves are shown by dots). K. V. Kostylev provided us with the data for these active curves.

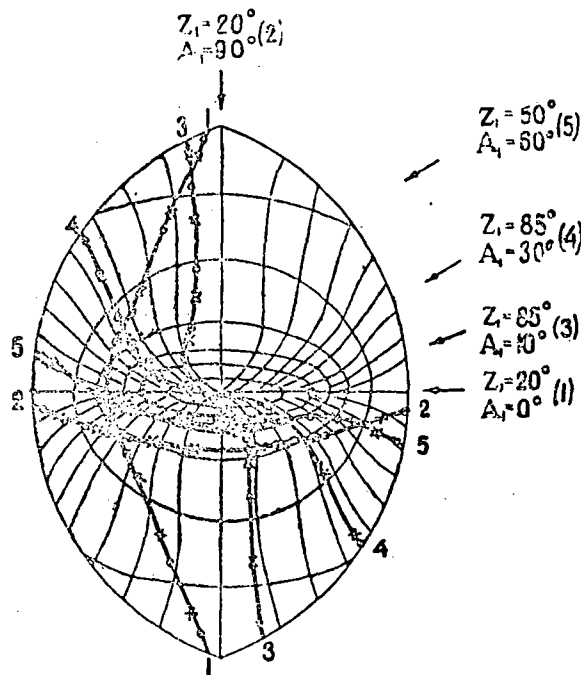


Figure 6. A comparative plot of active curves for five different radiant points, calculated on a computer (.) and obtained by the method cited (x).

Comparison of the corresponding curves in Figure 6 shows no significant deviations.

The accuracy with which the active radiant point curves are plotted using the proposed method will depend on the scope and accuracy of the calculation, and on the care with which the $Z_0 A_0$ coordinate grid and Figures 4 and 5 are constructed.

The proposed method can be used to plot a curve from 15 to 30 points in 5 to 10 minutes, and this is comparable in time to that required to calculate them using a "Nairi" computer. It takes about 7 to 10 hours to calculate the number of points indicated for an active curve using conventional calculating machines.

The following conclusions can be drawn from the foregoing.

1. A new graphical method of determining the active radiant curve is proposed, one making it possible to quite rapidly and simply find the positions of reflecting points on an $R + h$ sphere.

2. The graphical method of determining the active radiant curve, together with the graphical method for determining the geometric parameters of meteor burst propagation [3], enables us to solve a number of problems that earlier required extremely cumbersome calculations.

In conclusion, the author expresses appreciation to Lecturer K. V. Kostylev for providing the material needed to check the method, for reviewing the manuscript, and for valuable advice.

REFERENCES

1. Haynes, C. O., "Daily Variation in the Number of Meteor Showers Observed During Forward Scattering of Radio Waves," Sb.: Meteornaya radiosvyaz' na UKV [Collection: Meteor Radio Communication on UHF], IL Press, Moscow, 1961.
2. Mix, M. L., James, G. C., "The Effect of the Distribution of Meteor Radiant Points on the Efficiency of Communication Systems Using Meteor Scattering," Sb.: Meteornaya radiosvyaz' na UKV [Collection: Meteor Radio Communication on UHF], IL Press, Moscow, 1961.
3. Kalinina, N. N., "A Graphical Method of Determining the Geometric Parameters of Meteor Burst Propagation," Sb.: Meteornoye rasprostraneniye radiovoln [In collection: Meteor Propagation of Radio Waves], No. 3-4, KGU Press, Kazan', 1966.

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